GRANADA UNIVERSITY (UGR)

THEORETICAL PHYSICS AND THE COSMOS DEPARTMENT

ANDALUSIAN INSTITUTE OF GEOPHYSICS AND PREVENTION OF SEISMIC DISASTERS

SIGNAL THEORY, TELEMATICS AND COMMUNICATIONS DEPARTMENT

"Shannon Entropy estimator for Characterization of Volcanic Seismic Signals with Python Software"

(*Estimador de entropía de Shannon para la caracterización de señales sísmicas volcánicas con software Python*)

USER MANUAL: VERSION 1.1

Autor:

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Masaya Volcano, Nicaragua
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General índex

1.- Introducción

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The "*Volcano-Seismic signals entropy analysis system*" It constitutes a user-friendly interface that allows easy and efficient management for working with the most commonly used seismic signal formats in observatories, such as formats: (*SEISAN, GSE2, EVT, GCF, WAV, MSEED, and SAC, among others*). The system consists of several independent modules that perform actions such as reading, signal filtering through one or three components, displaying graphs of the original and filtered signals, calculating Shannon entropy (original and normalized), the envelope of Shannon entropy, calculating Kurtosis and the frequency index, and presenting a comparison of the envelope by calculating five types of frequency intervals in a selected filter. This procedure provides practical assistance in some observatories that need specific programs and software, which can sometimes be complicated, to perform reading, calculation operations, and presentation in various formats. This is partly because data acquisition is done through external sites, which the operators do not manage or control, or they are provided by other observatories whose operation formats differ from those that will be processed and analyzed at the receiving observatory. For these reasons, it is important and extremely useful for the human operator to have a system that performs the calculation of parameters such as Shannon entropy, Kurtosis, and the frequency index (complemented by their respective envelopes), obtaining results in a more reliable and straightforward manner. In this way, they provide much more information about the processes (pre-eruptive and post-eruptive) of volcanoes, leading to better early warning systems.

The system to carry out all the mentioned aspects consists of three independent modules:

1. **Signal Reading and Filtering Module:** (Read, filter, and represent seismic signals), either using one or three components.
2. **Calculation and Presentation Module of Shannon Entropy:** This includes the calculation and presentation of Shannon Entropy (original and normalized), Frequency Index, and Kurtosis, along with their respective envelopes, based on analysis windows (10 minutes, one hour, and twenty-four hours).
3. **Module for Reading, Filtering, and Graphs of Shannon Entropy Envelope:** This module is responsible for reading, filtering, and graphically displaying the envelope of Shannon entropy through the filtering of various frequency intervals.

IMPORTANT NOTE: For proper reading and processing in the modules of the records, the folders containing them must be indicated or numbered in Julian days (001-365). Regardless of the body of the name that precedes it. Valid examples include; *(UC.INCA..HHZ.D.2020.**001** - NU.TELN.00.EHZ.D.2020.**280** - C7.PLPI..HHZ.D.2022.**004**).*

The system has been developed in the Python programming language, version 3.8.6. (The library set is compatible with version 3.10.10). Additionally, a series of open-access libraries are included which, in conjunction with Python, work to enable the use of graphical and analytical tools, providing simplicity in use and increasing computational power for the user. Listing some of the main elements and libraries used here, they include:

1. **NumPy:** A library for numerical operations in Python. . (https://numpy.org/doc/stable/user/quickstart.html)
2. **Matplotlib:** Used for creating static, animated, and interactive visualizations in Python. (https://matplotlib.org/stable/users/index.html)
3. **PyQt5:** A tool that links with the graphical library Qt5 in C++. (https://pypi.org/project/PyQt5/)
4. **ObsPy:** A Python toolbox for seismology. (https://docs.obspy.org/)

These libraries, among others, contribute to the functionality of the system, making it user-friendly and enhancing its computational capabilities. Another key feature of the system is its definition as a cross-platform application, meaning that it can operate under various platforms or operating systems, such as Windows (*7, 8, 10, 11*) in both 32-bit and 64-bit versions. Additionally, it is designed to work on Linux systems like Ubuntu and similar distributions (*Debian, Red Hat, Fedora, SUSE, etc.*), Mac, or Android for tablets and mobile devices (*with prior adaptation of Python for these devices*).

NOTE: In the appendices of this document (*as well as in the Readme.txt and Initials_requirements.txt files*), you can find information on general aspects of installation on Windows and Linux systems. It provides guidelines for installing the main programs and additional libraries that Python requires to correctly execute the programs developed in its environment.

2.- System Initial Screen

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To install the system on Windows[1], you basically need to perform two actions:

a) Copy the "*EntropySis1*" folder in "My Documents" in Windows.
b) Copy the "*EntropySis1.bat*" file to the Windows "Desktop".

Beforehand, install Python and the additional Python libraries, the instructions for which are found in the "Initials_requirements.txt" file or at the end of this document (*see Appendices A and B, Pages 70-75*). Once you have copied "EntropySis1.bat" to the desktop, right-click and select "Run as administrator."

Fig. 1 Pop-up window when right-clicking the file "EntropySis1.bat"

On the screen that opens, click the "**Yes**" button when asked, "*Do you want to allow this app to make changes to your device?*" This is a warning message. However, the application doesn't make any changes, so you should trust its execution.

Upon clicking "**Yes**," the following command window opens, indicating the welcome to the system.

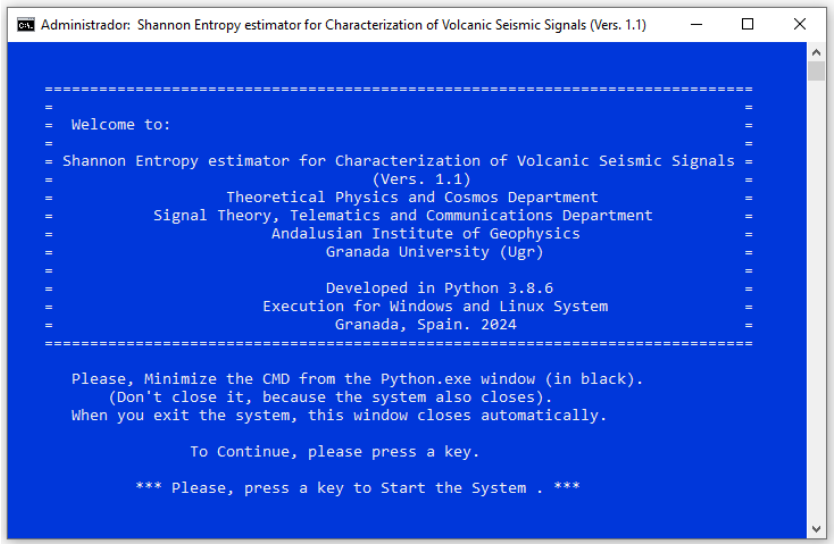


Fig. 2 Welcome Screen to the Entropy Analysis System for Seismic-Volcanic Signals.

After reading the instructions in the window, you just need to press any key to access the initial screen of the system. The system should already be copied to "***My Documents***" and the additional libraries installed. With this, the "EntropySis1.bat" file contains all the program loading instructions.

[1] To install the system on Linux or Mac operating systems, please refer to the "*README.txt*" file and the appendices in this document.

The initial screen of the system is "***Menu1.py***". It is displayed when any key is pressed on the Welcome screen. Additionally, the Python console window (*a screen with a black background*) appears, similar to the following:

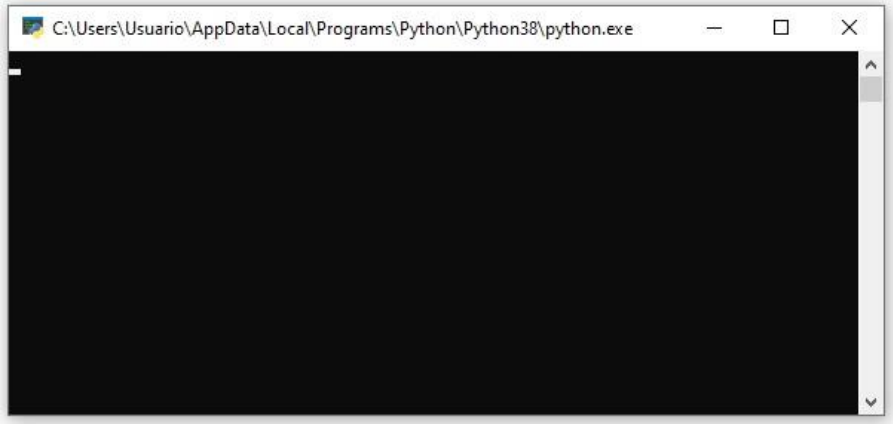


Fig. 3 Python Console (CMD) Window (*Should be minimized*)

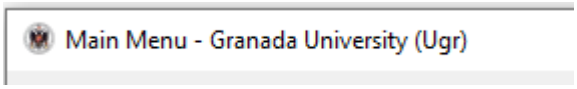
To prevent it from obstructing the view, you can and should "***minimize***" the console window. **Do not close it**, as doing so would also close the system's startup window. Upon exiting, after completing tasks with the system, this window closes automatically. The initial screen "Menu1.py" (*which provides access to the system's modules*) looks like the following:

Fig. 4 Initial screen "Menu1.py", introduction and main menu of the system.

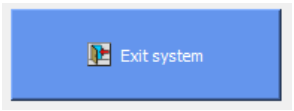
2.1.- Elements of the Initial Screen ("Menu1.py")

As observed in the above figure, the initial or presentation screen is a simple window composed of: Three command buttons for accessing modules, and in the bottom left corner, the system exit button.

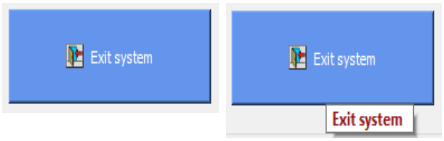
a) The name and icon of the University is visible at the top.



b) At the bottom you can see the command button: "***Exit system***".



When the mouse pointer hovers over the button, a text appears indicating the action of that button (*Exit System*).



If you click the "*Exit system*" button, a window appears asking the user if they are sure they want to exit the system.

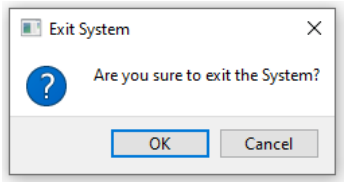


Fig. 5 Dialog Box asking if you want to exit the system.

If you click "*OK*" the screen closes, and the system exit is completed. If you click "***Cancel***," the initial menu continues. The menu contains three command buttons, each accessing a specific module of the system. The buttons are visible in the image below. Clicking each button provides access to the corresponding module. This is further explained in the following sections.

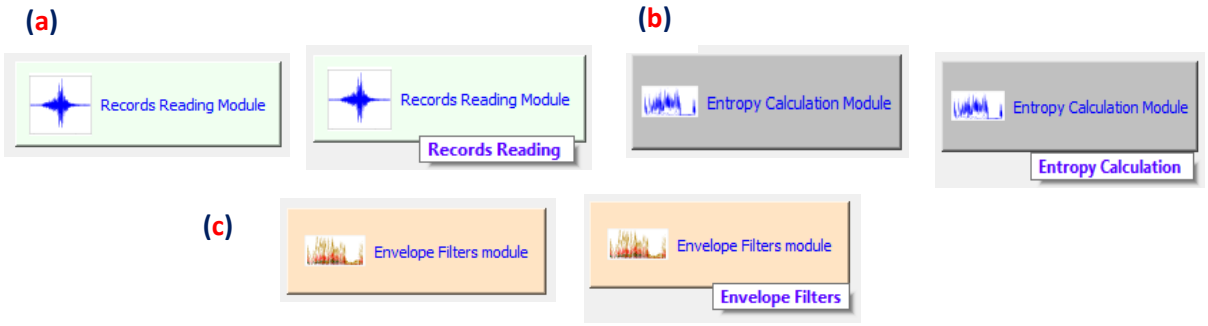


Fig. 6 Command Buttons for Accessing System Modules: **a**) Read and Plot Records, **b**) Calculation and Plotting of Entropy and Envelope, **c**) Reading and Plotting of Envelope by Filters.

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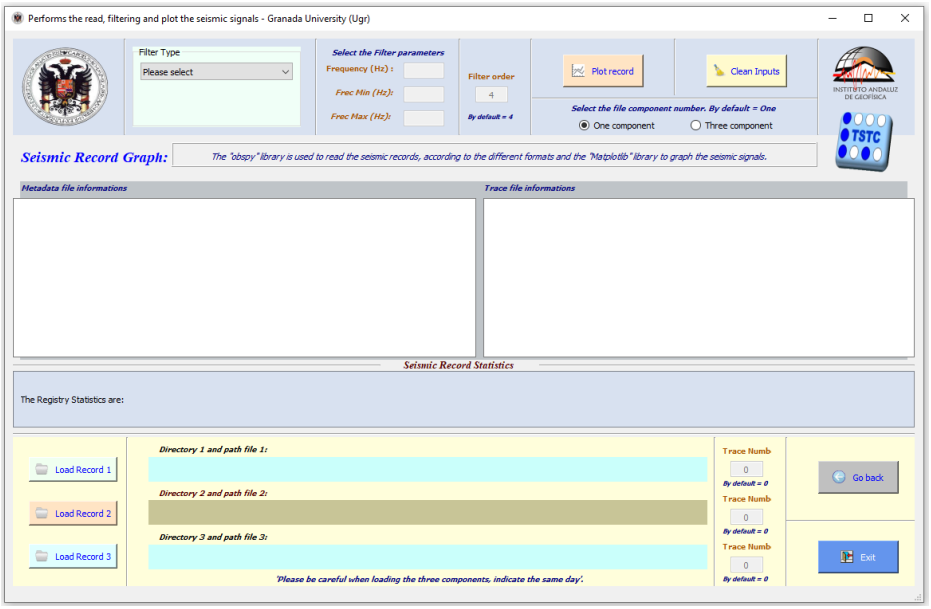
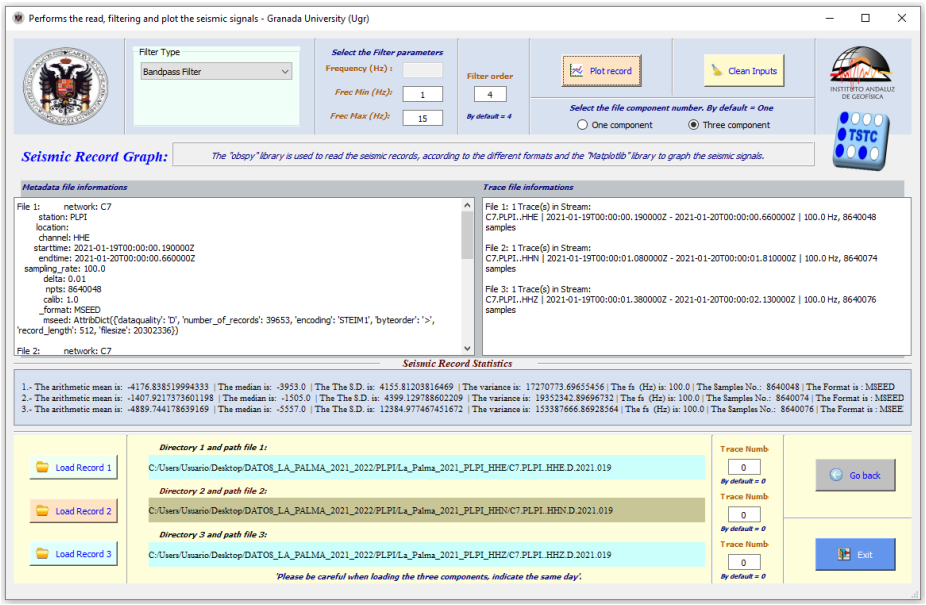
MODULE I

READ AND PLOT RECORDS





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3.- Read and Plot Records Module.

The module for reading and plotting records (ReadSignals.py) allows the reading, filtering, and plotting of seismic records. "Performs the read, filtering and plots the Seismic-signals." The main goal of this initial module is to obtain an initial visualization of the records to decide which folders of records will be used for calculating Shannon Entropy and its envelope. With this interface, graphs can be obtained using one or three components. Similarly, it allows the representation of graphs through various traces (if they exist), which compose some records like MSEED. The interface and its components are as follows.

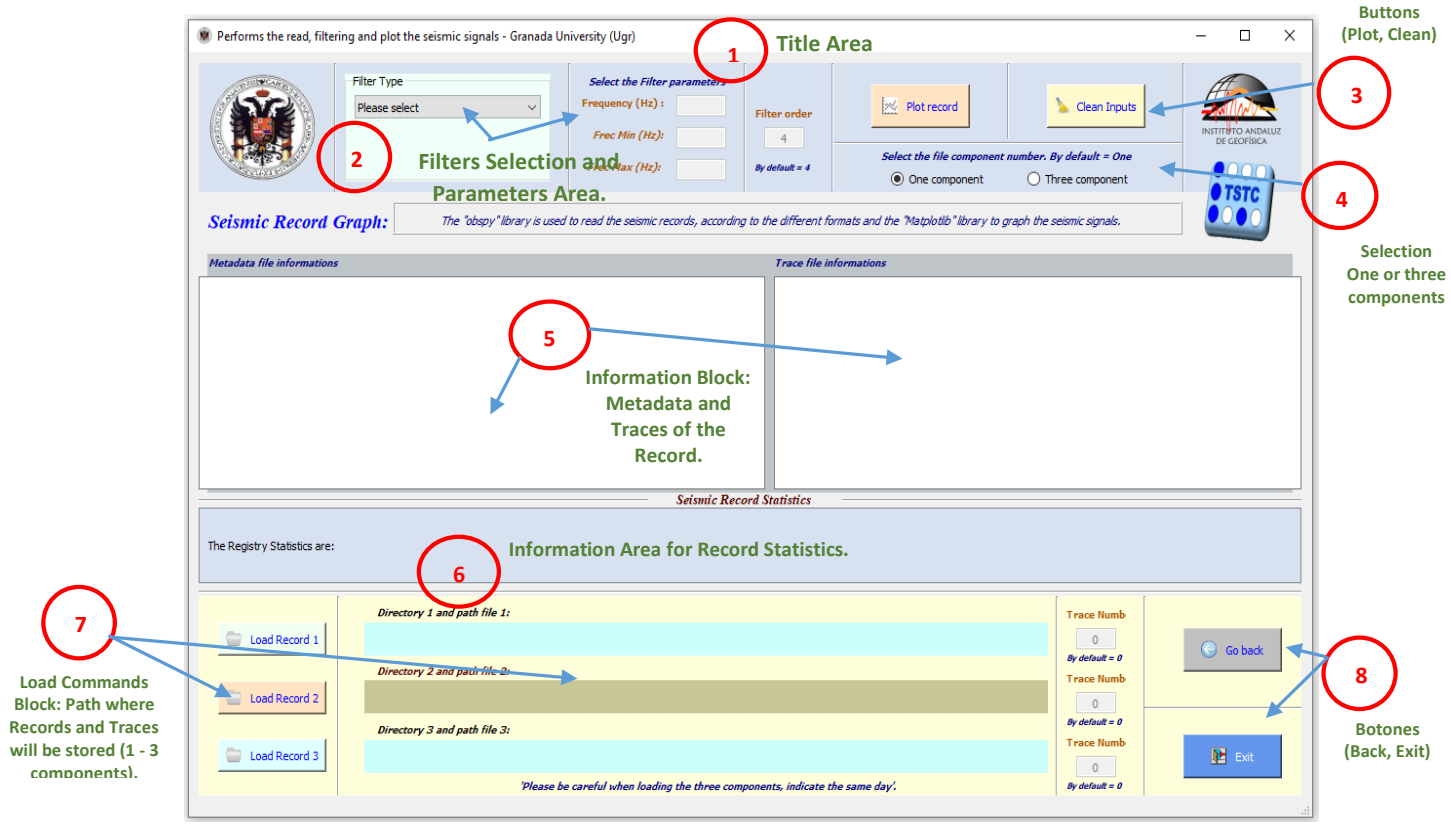


Fig. 7 Interface of the Module for Reading, Filtering, and Plotting Records and its Components.

As observed in the previous figure, the elements that make up this interface are as follows:

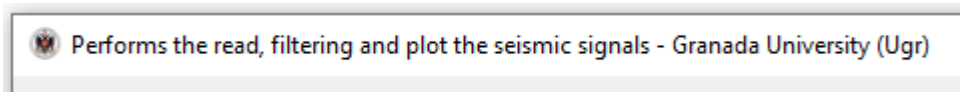
1) Title Area.
2) Filters Area.
3) Command Buttons for Plotting and Clearing Inputs (*Plot Record and Clean Inputs*).
4) Selection of One or Three Components.
5) Metadata and Trace Information Block for the Record.
6) Statistics Information Area for the Records.
7) Load Commands Block, Path where Records and Traces are Stored (*One or Three Components*).
8) Command Buttons for Go Back and Exit (Go Back and Exit).

3.1.- Elements of the Reading and Plotting Records Module:

The elements that make up the main screen are detailed below:

3.1.1.- Title Area. 1

At the top of the module's interface screen, the following is indicated: The program's name, icon, and the University's name as the title. (1).



In addition to the title area, number (1), various elements of the interface are observed, enumerated from (2-8) in the red circles. Each of these elements will be described below:

3.1.2.- Filters Area. 2

They consist of three sections, marked in the green circles in the following picture.

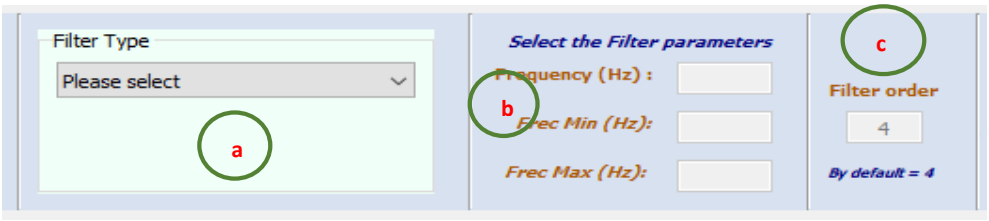


Fig. 8 Filters Area. In the green circles: **a**) Filter type selection, **b**) Filter parameter selection, **c**) Filter order selection.

a) **Filter Type Selection:** Four filter types are available to choose from: (Lowpass[2]), (Highpass[3]), (Bandpass[4]) and (Bandstop[5])

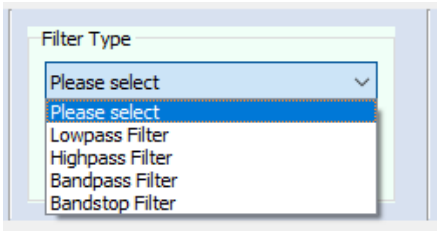


Fig. 9 Filter Type Selection

At the beginning, by default, it is set to "*Please Select*." Once the user determines or chooses a filter to use, the input parameter boxes (**b**) will be activated according to the type of selection.

IMPORTANT NOTE: Entries in each box are validated to receive only numeric input; entering alphabetic characters or letters is not allowed. Likewise, values are centered in the box, and each value corresponds to the element being entered. For example, the filter order box only accepts integer values up to two digits, while the frequency boxes accept decimal values.

---

[2] **Lowpass Filter:** The lowpass filter blocks high-frequency signals and allows low-frequency signals to pass through (*frequencies lower than the cutoff frequency*).

[3] **Highpass Filter:** The highpass filter blocks low-frequency signals and allows high-frequency signals to pass through (frequencies higher than the cutoff frequency).

[4] **Bandpass Filter:** The bandpass filter allows spectral content only in the vicinity of the central frequency. This window is created through a minimum frequency value and a maximum frequency value. It eliminates noise associated with low and high frequencies generated and/or residual.

[5] **Bandstop Filter:** The bandstop filter does not allow the passage of signals whose frequencies are between the upper and lower cutoff frequencies. In other words, it eliminates frequencies or stops a particular frequency band.

b) **Filter Parameter Selection:** In the case that the user selects the lowpass (*Lowpass*) or highpass (*Highpass*) filter, the frequency box will be activated, part (**a**) of the figure below, and the other boxes remain deactivated. If the user selects the bandpass (*Bandpass*) and bandstop (*Bandstop*) filters, the minimum frequency and maximum frequency boxes will be activated, part (**b**) of the figure below. The frequency box remains deactivated. The input values for the data (*centered*) in these boxes are validated to receive decimal numbers.

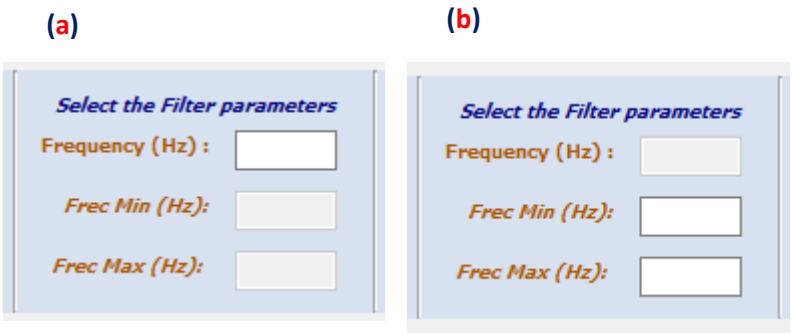


Fig. 10 Selection and entries of parameters according to the selected filter type: (a) **Frequency Box:** For lowpass (Lowpass) and highpass (Highpass) filters and (b) **Minimum Frequency and Maximum Frequency Boxes:** For bandpass (Bandpass) and bandstop (Bandstop) filters.

c) **Filter Order Selection:** By default, the filter order is initially deactivated and set to a value of 4 (*See Figure 11*). When selecting any of the four available filter types, this box is activated, allowing the user, if desired, to change the filter order value. The input values for the data (centered) in this box are validated to receive only integers up to two digits.

Fig. 11 Selection and Entry of the Filter Order Parameter. By default, its value is set to four (the user can modify the value of this parameter if deemed necessary).

3.1.3- Plot and Clear Inputs Command Buttons. (*Plot Record y Clean Inputs*)

3

In this section, there are command buttons that allow for the creation of the plots "*Plot Record*" (**a**) and clearing of inputs "*Clean Inputs*" (**b**).

Fig. 12 Command buttons for creating plots (*Plot Record*) (**a**) and clearing inputs (*Clean Inputs*) (**b**). The texts presented by the buttons when the cursor is placed over them are visible.

a) "***Plot Record***" **Command Button:** Initiates the creation of plots once all input parameters have been defined. By default at the beginning, this button is deactivated. It will only be activated when the user selects the type of filter they want to implement with the records.

NOTE: Later in this document, the complete action of the button is described (See Section 3.3).

b) "***Clean Inputs***" **Command Button:** Clears or erases input elements. Additionally, it closes existing plots and resets the analysis screen to its initial state, ready for a new search and analysis of seismic events.

There is a validation in the execution of this button to prevent any accidental deletion that the user might perform with the input parameters. When clicking this button, a dialog box appears, asking the user if they really want to erase the entries they have made. This window is as follows:

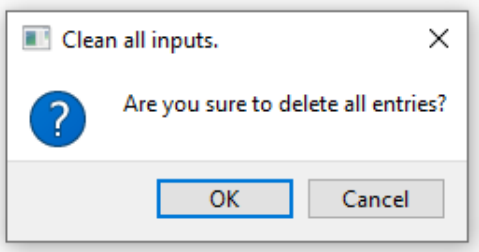


Fig. 13 Verification Dialog Box for User-Initiated Input Deletion.

As observed in the figure, if the user indeed wants to delete the entries, they click the "*OK*" button, which will erase all entries and reset the module interface screen to the initial values, with the boxes deactivated. If, on the other hand, the user does not want this, perhaps due to an error or oversight, they can click the "*Cancel*" button, and the execution will return to the main interface screen.

3.1.4.- Selection of One or Three Components. 4

In this section, the user can choose between analyzing one or three components of seismic records.

Fig. 14 Selection of One (**a**) or Three Components (**b**) to analyze.

By default, as indicated by the message, it is initially marked to work with one component (**a**). The user can choose to work with three components (**b**) by checking the corresponding box. When selecting either one or three components, one or three command buttons for loading records will be activated, as well as one or three boxes for the corresponding traces (*See Section 3.1.7*).

3.1.5.- Block of Information: Metadata and Traces of the Record. 5

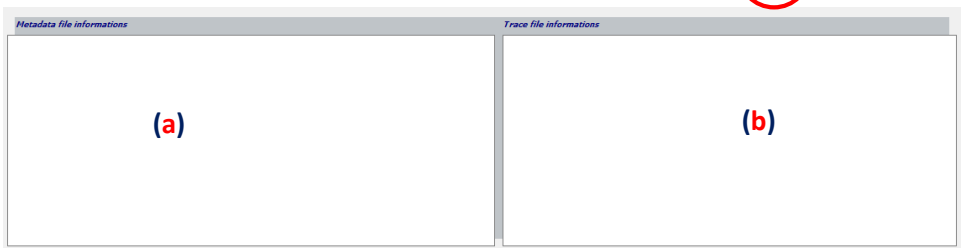


Fig. 15 Image of the section that presents the information contained in the records: **a**) "*Metadata*" and **b**) "*Record Traces*".

In these two blocks, the results of the analyses related to metadata (**a**) and traces of the records (**b**) are presented. Something important to highlight in the "*Metadata and Record Traces*" section is that this area is editable, meaning that you can select and copy the information, then paste it into a Notepad, Word file, etc. If the number of traces of the records (**b**) is varied or more than one, you can copy and paste this information into an Excel file, thus creating a table indicating the number of traces for easier selection later on (*See Section 3.3, step "c"*). This way, you can consult or use the information contained in the records later. The information will be automatically presented when clicking the "*Plot Record*" command button. By using the "*Clean Inputs*" button, the information in these sections will be deleted.

3.1.6.- Information Area for Record Statistics. 6

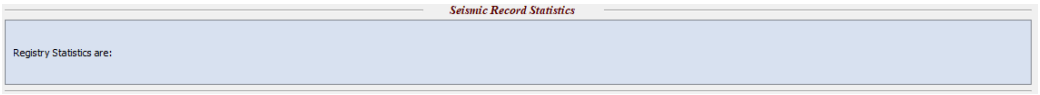


Fig. 16 Visualization Area for Record Statistics.

In this area, the general statistics of the records are presented. The elements that constitute this information are as follows:

a) The seismic network that recorded the data.
b) The station of that network that recorded them.
c) The location.
d) The channel through which the data were recorded.
e) Initial recording time.
f) Final recording time.
g) Sampling frequency.
h) Number of samples in the record.
i) Record Format Type.

3.1.7.- Load Commands Block: Path where Records and corresponding Traces are stored (One or Three Components). 7

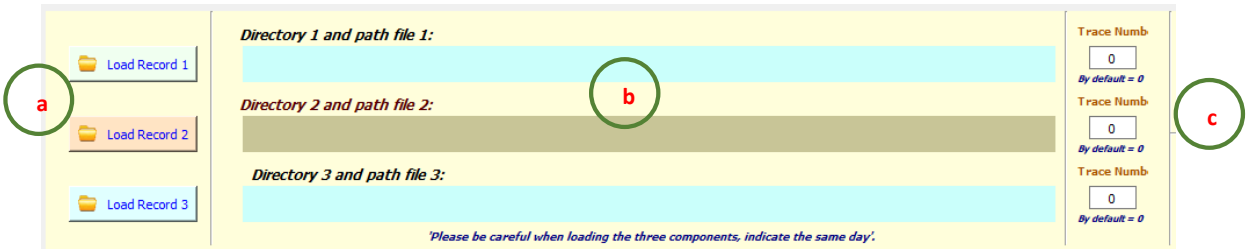


Fig. 17 Section of the Load Records command block: (**a**) Presentation of the directory or physical path where the record is stored, (**b**) trace number of the record and (**c**) In either case, whether it's one or three components.

a) **Load Commands Block:** This section of the block presents the command buttons for loading records, with one or three components.

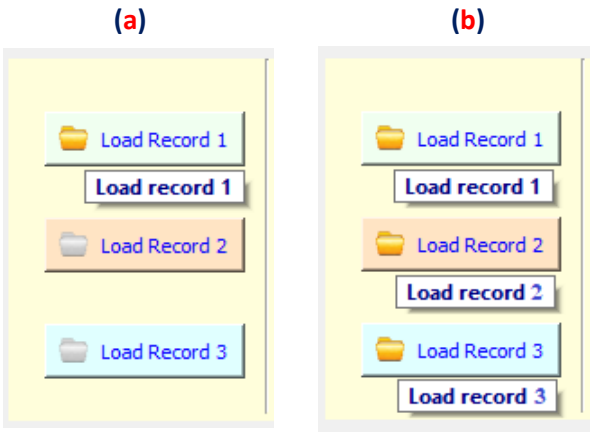


Fig. 18 Section of the command buttons that allow the loading of records. (a) For loading records with one component, (b) For loading records with three components.

By default, these command buttons are initially disabled and will be activated when the type of filter to be used is selected, depending on whether the checkbox for one or three components is marked. As seen in part (a) of the figure, it shows the loading of the seismic record in one component. This happens when in the previous section 3.1.4 the checkbox for one component is selected. In this case, only the first command button for record 1 is activated, and the other two command buttons for records 2 and 3 are disabled. On the other hand, in part (b), it can be observed that all three command buttons have been activated. This occurs when the checkbox for three components has been selected in section 3.1.4.

Clicking any of these buttons opens a Windows dialog box asking for the location where the record to be loaded is stored. This window is similar to the following:

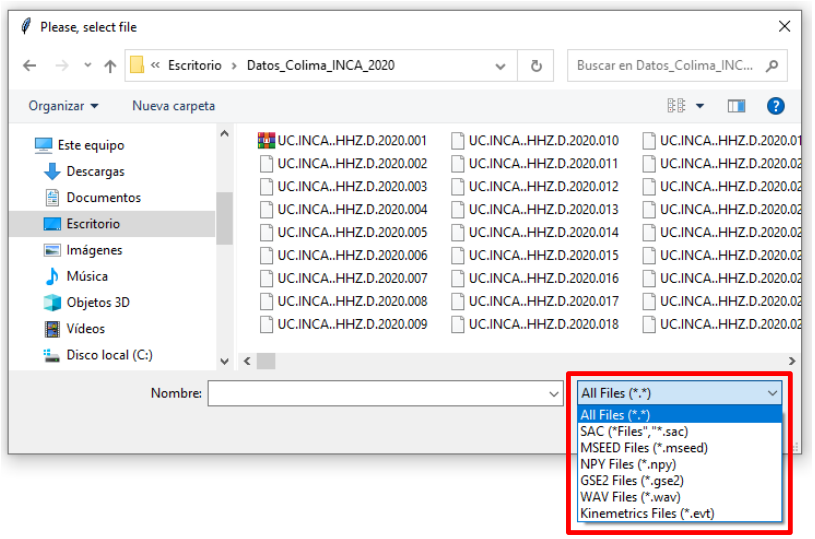


Fig. 19 Screen for selecting records to load.

The action of the "***Load Record***" button allows, upon clicking, the opening of an explorer window (*by default, the path is in the root directory "**C**" of the PC*), presenting options for various available formats (***red box***) and allowing for a search in the computer directory.

On the screen in figure 19 (*the language is determined by the operating system*), records are selected according to the desired format (*SAC, MSEED, GSE2, EVT, etc.*). This is possible through the seismic format reading library "**Obspy**". Upon selecting the record, it is displayed in the "*Name*" box on the screen, and you can click the "*Open*" button (*red box*) for the record in the selected directory to be loaded.

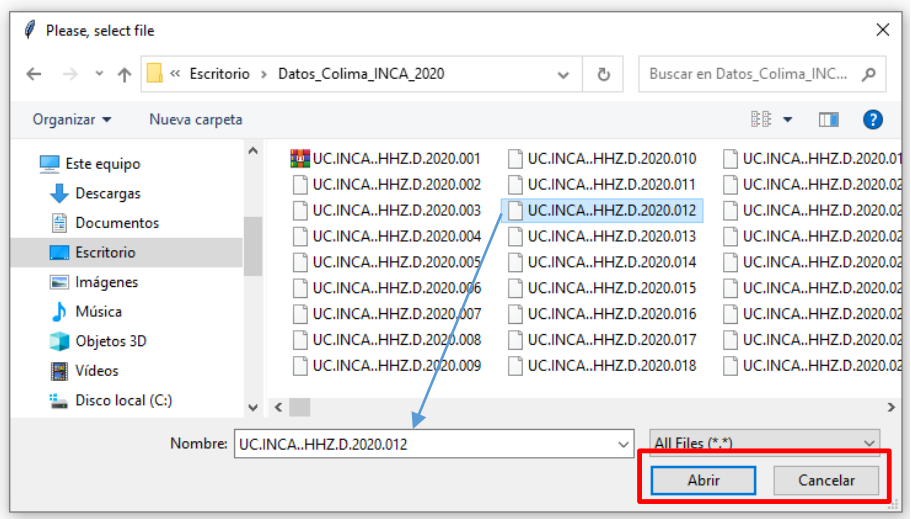


Fig. 20 Screen for selecting a record

Therefore, after selecting the record, click the "*Open*" button, and the record is loaded, and this path is displayed in the loading area to the right of the button (*part "b", described below*). Otherwise, click the "*Cancel*" button, and the action returns to the analysis screen.

b) Path Area where the records are stored: This second section of the block presents the physical path where the directory and the record (*whether one or three components*) are located for analysis (*after having selected it through the command button in the previous section*).

In this way, three spaces are reserved to present the information, depending on whether one or three components of the records are being worked on (*File 1, File 2, and File 3*).

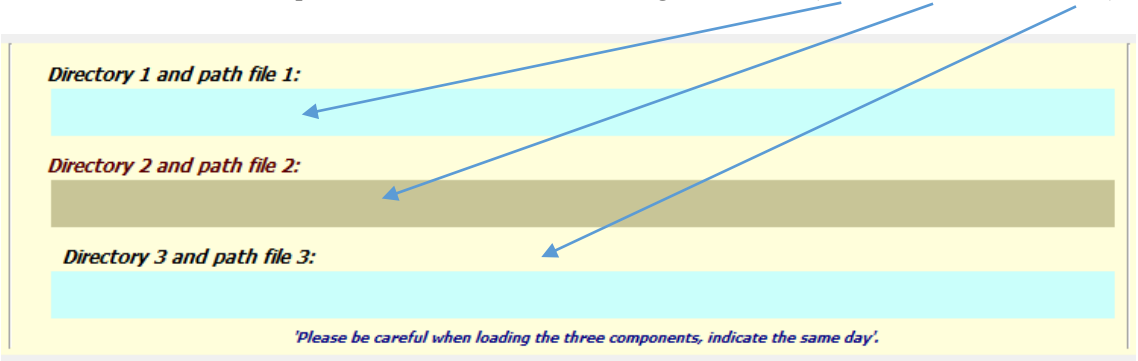


Fig. 21 File path boxes that show the physical location of the records.

NOTE: As indicated by the message at the bottom of the previous figure, care must be taken when selecting the three components to indicate the same day for all three components: North-South, East-West, and Vertical.

c) Section for the Corresponding Traces (one or three components): The third section of the block indicates the trace number for each record. It is shown in the following figure.

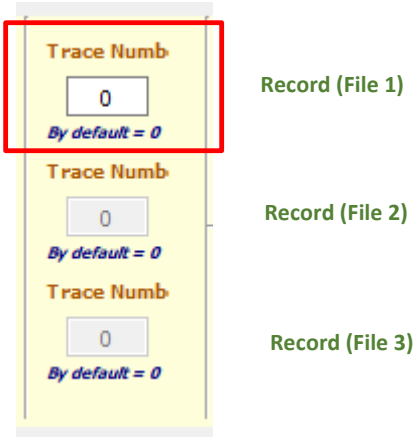


Fig. 22 Text boxes that show the number of traces for the records. The default value is zero "0".

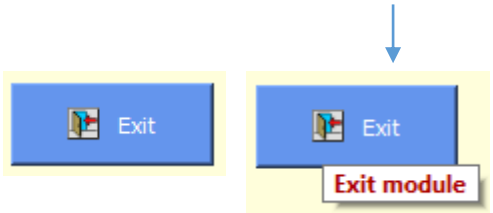
As seen in the image, by default, the initial value of the trace number is zero "**0**". In case the record has more than one trace (*in the case of multiple records like MSEED*), the trace number to be displayed is indicated in the text box. Each box corresponds to one record; in the image, one record (*Record 1*) has been designated (*red box*), while the next two boxes (*Records 2 and 3*) are disabled. When selecting three components, these text boxes become active, allowing you to input the corresponding trace number if desired. The validation for these boxes ensures they only accept numbers up to three digits.

3.1.8.- This section includes two command buttons: "Go Back" and "Exit." 8

This last block consists of the following elements:

a) Command button "***Go Back***": Allows you to return to the initial presentation screen of the system (*Main Menu*). When you hover the mouse pointer, it displays a message indicating its function.

b) Command button "Exit": Allows the complete exit from the module and system (after presenting the screen that asks if you want to leave the system). When you hover the mouse pointer, it displays a message indicating its function.



In the same way as on the home screen, if you click the "Exit" button, a window will appear asking the user if they are sure they want to exit the module and system.

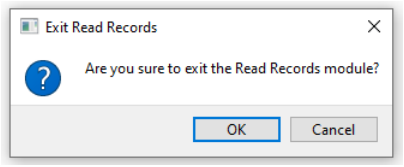


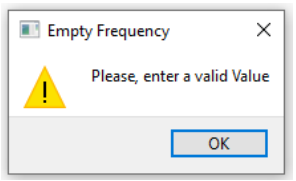
Fig. 23 Text box indicating whether you want to exit the module and system.

Clicking "*OK*" closes the screen and completes the exit of the module and system. Clicking "*Cancel*" will continue on the analysis screen.

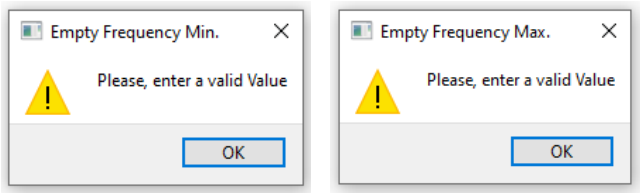
3.2.- Dialog boxes for validation of errors in records or entries.

In case you want to plot, i.e., click the "*Plot record*" button without entering data in any of the input text boxes, a validation will be displayed. It shows a warning or error dialog box indicating that some action needs to be taken to correct the inputs. Additionally, these dialog boxes allow the program execution to continue without severe interruption due to lack of data. The validations for incorrect inputs are as follows:

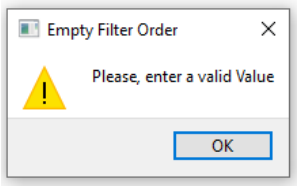
a) Validation for data entry - empty frequency.



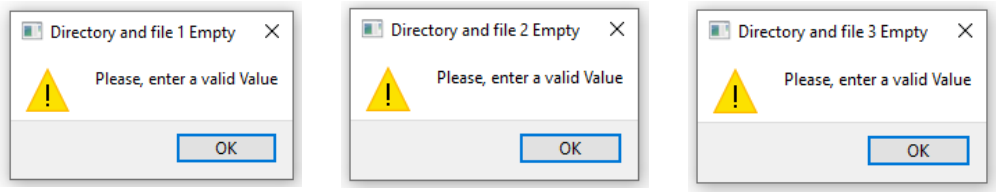
b) Validation for data entry - empty minimum and maximum frequencies.



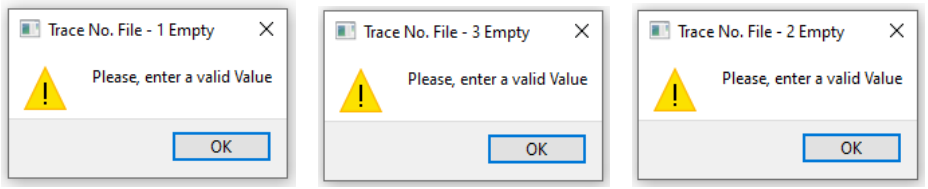
c) Validation for data entry - empty filter order.



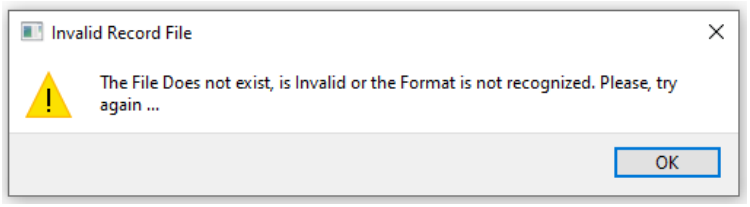
d) Validation for data entry - empty directories and files.



e) Validation for data entry - empty trace number.



f) Validation in case of encountering a different input error than the ones mentioned earlier, such as a non-existent or invalid file.



The message in the above figure indicates an input error (*different from the previous ones*) because the format is not recognized, it is invalid, or the record does not exist. Additionally, the parameters or inputs may be outside the allowed range according to the signal to be analyzed. By clicking the "*OK*" button, you return to the system to choose a valid file or correct the erroneous inputs. This way, the program's execution continues without issues.

3.3.- Proceso de ejecución y resultados del módulo de lectura y gráficos.

The process to load, filter, and plot a record, whether it's a single or three components, is very easy and consists of the following steps (*It is recommended to follow these steps*):

a) Select whether you want one or three components (*by default, one component is indicated*).
b) Select the filter type (*Lowpass, Highpass, Bandpass, or Bandstop*).
c) Enter the parameters for the selected filter type. For Lowpass and Highpass filters, enter a valid "*frequency*" value. For Bandpass and Bandstop filters, enter valid values for minimum and maximum frequencies.
d) Enter the filter order if required, or leave the default value = 4.
e) Click the "*Load Record 1*" button to select the record to load. In the Windows dialog box, browse or select a specific record. By default, the initial path is in the root directory "**C**" of the PC (*whether it's Windows or Linux*). Once selected, click the "*Open*" button (the file path is displayed in *Directory 1 and path file 1*).
f) Enter the trace number of the record or leave the default value = 0.
g) Click the "*Plot record*" button to plot the record and display the record information.

The description of the previous process is for one component. In case you select three components, you will need to select three records (one for each component), ensuring to select records from the same day for all three components. Similarly, indicate the trace number if required or leave the default value = 0.

Once the above steps are completed, in the final step (g), click the "*Plot record*" button. The output of this process will consist of graphs showing the original signal and the filtered signal. You can *zoom (see Section 6, point 5)* in on any part of the graphs, whether in the original or the filtered signal. The graphs are synchronized to automatically adjust and display the same zoom in both. Later, you can save the resulting graph in any of the various available formats.

3.3.1.- Example of Reading Procedure for One Component.

As an example, the following process in the interface with the output elements for a single component is presented.

a) Interface and graphical output for a single component.

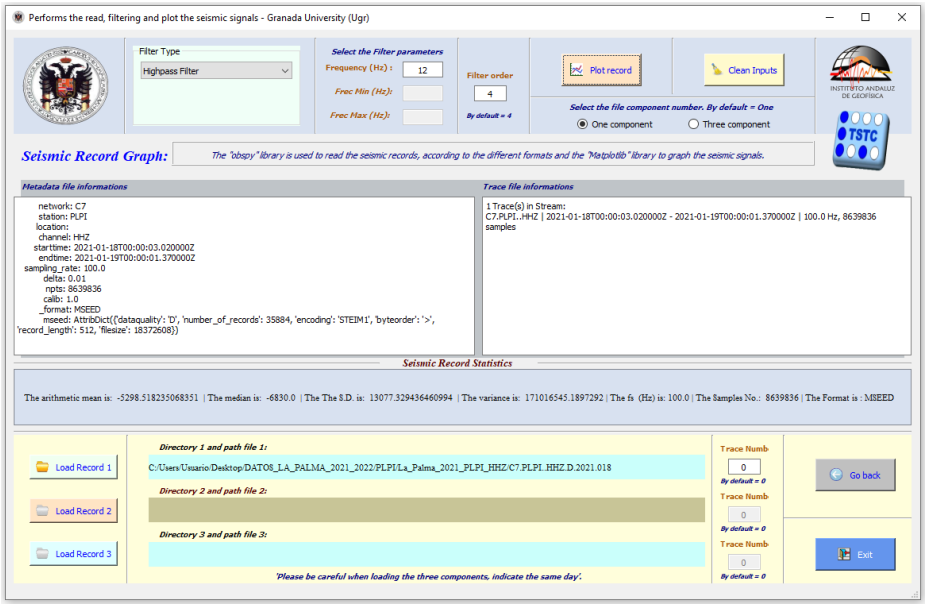


Fig. 24 Outcome of selecting a record with a single component (vertical), using a high-pass filter of 12 Hz. The default values for filter order = 4 and trace number = 0 have been retained.

In the previous figure, the values obtained when loading the single-component record are observed. The input parameters used are: High-pass filter = 12 Hz, Filter order = 4, Trace number = 0. The last two parameters are the default values. The user has only entered the data of the desired file or record selection and the type and value of the filter. The information of the "metadata" and the trace of the record is observed, which in this case consists of a single trace, i.e., the value zero (*trace values start from zero*). Also, the statistics of the record are displayed. The record is one day long, equivalent to 86,400 samples or seconds. The resulting graph is as follows.

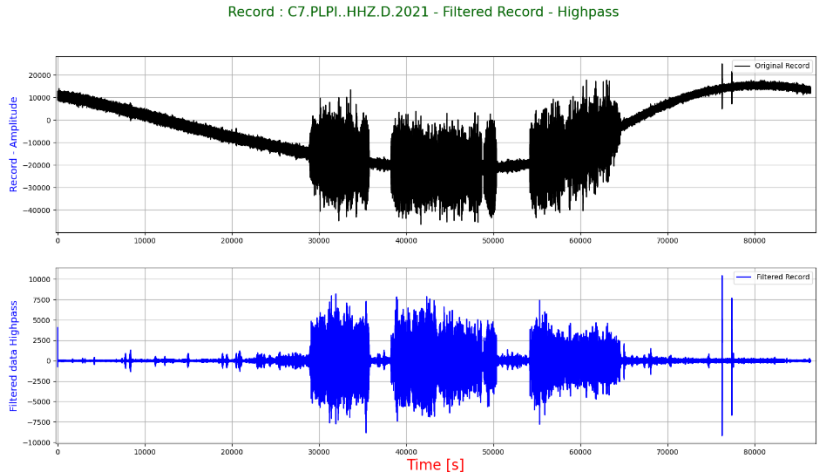


Fig. 25 Graph resulting from the previous process. The upper part shows the original signal, and the lower part shows the filtered signal.

3.3.2.- Example of the reading procedure for three components (*one and multiple traces*).

As an example, the following process of the interface with the output elements for three components is presented.

a) Interface and graphical output for three components with an equivalent trace.

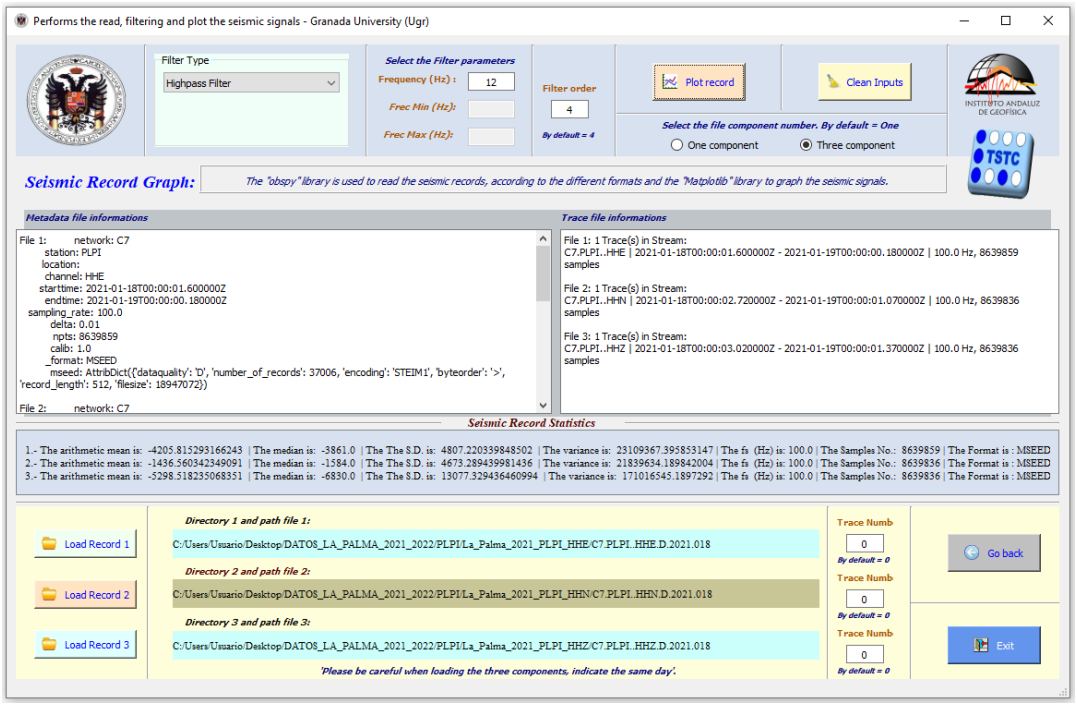


Fig. 26 Result of selecting a record with three components (*East-West, North-South, and Vertical*), using a high-pass filter of 12 Hz. Default values for filter order = 4 and trace number = 0 have been used.

In the previous figure, the same record from January 18th has been loaded for each of the components (*HHE, HHN, and HHZ*). The corresponding values for each record are observed in the metadata, traces, and statistics areas. Since the records consist of a single trace, the default value of zero is used. The resulting graph of this process is as follows.

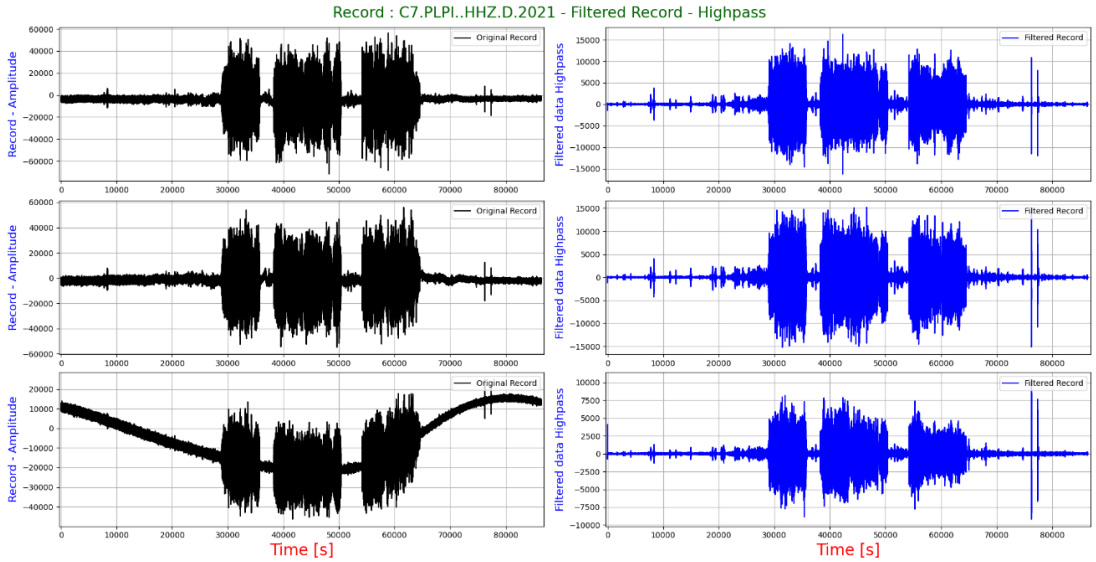


Fig. 27 Graph resulting from the previous process. On the left, the original signals of each component, and on the right, the filtered signals of each component.

b) Interface and graphical output for three components with various and different traces.

In case of dealing with records with more than one trace, the user must decide which trace to choose. This is the case in the following example, with an MSEED record that consists of multiple traces, and in which, within the same record, all three components are present, each in a different trace.

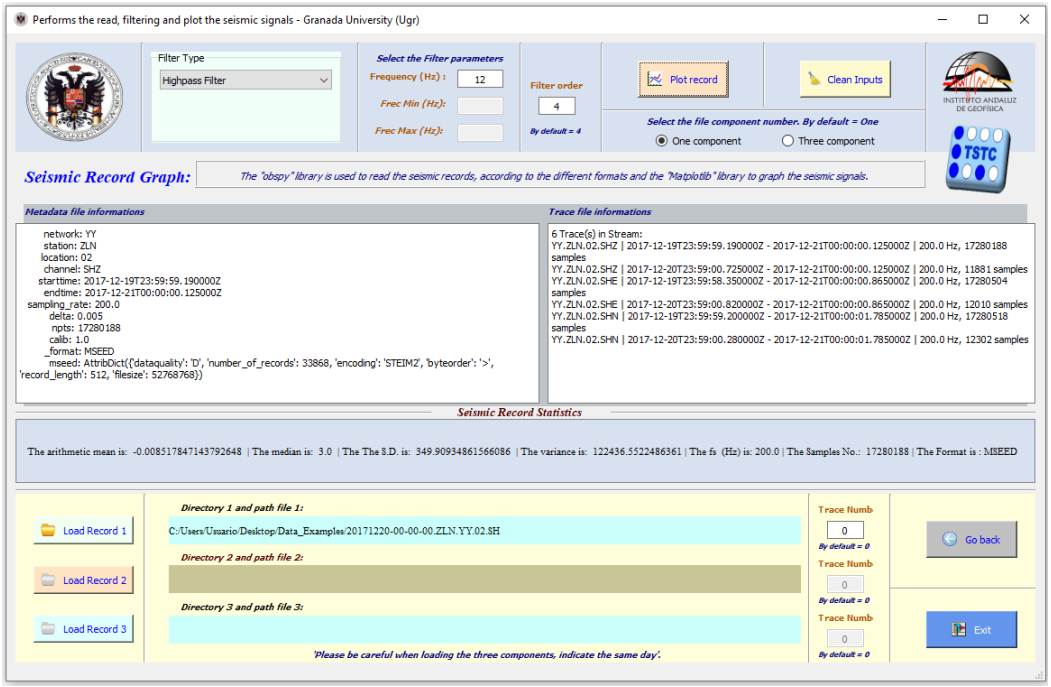


Fig. 28 Result of selecting a record with one component, which has different traces, using a high-pass filter of 12 Hz. The default values of filter order = 4 and trace number = 0 have been left unchanged.

In the above figure, the same record has more than one trace. Additionally, the three components are included in the same record but in different traces. Initially, this result has been presented when analyzing the record with one component, which would result in multiple traces. In this case, it is useful to copy and paste the trace information into an Excel file to count which trace number corresponds to the component. This example is simple, as it only has six traces, but sometimes there are records with more than 70 traces, so analyzing them in this way is helpful. Therefore, in the example, the same record has been loaded into each box, but indicating a different trace corresponding to the appropriate component. The traces with a higher number of samples (*more information*) are: (**0**) vertical component, (**2**) east-west component, and (**4**) north-south component. This can be easily indicated by copying the traces and creating a table in Excel, as shown below. The selected trace numbers (*0*, *2*, and *4*, corresponding to components *SHZ*, *SHE*, *SHN*) have been marked.

Trace Number	Record
0	YY.ZLN.02.**SHZ** | 2017-12-19T23:59:59.190000Z - 2017-12-21T00:00:00.125000Z | 200.0 Hz, 17280188 samples
1	YY.ZLN.02.SHZ | 2017-12-20T23:59:00.725000Z - 2017-12-21T00:00:00.125000Z | 200.0 Hz, 11881 samples
2	YY.ZLN.02.**SHE** | 2017-12-19T23:59:58.350000Z - 2017-12-21T00:00:00.865000Z | 200.0 Hz, 17280504 samples
3	YY.ZLN.02.SHE | 2017-12-20T23:59:00.820000Z - 2017-12-21T00:00:00.865000Z | 200.0 Hz, 12010 samples
4	YY.ZLN.02.**SHN** | 2017-12-19T23:59:59.200000Z - 2017-12-21T00:00:01.785000Z | 200.0 Hz, 17280518 samples
5	YY.ZLN.02.SHN | 2017-12-20T23:59:00.280000Z - 2017-12-21T00:00:01.785000Z | 200.0 Hz, 12302 samples

Table 1. Trace Number of the Record, indicating the three components to which they belong. The traces (0, 2, 4) and components (SHZ, SHE, SHN) are marked, where the highest number of samples, i.e., the most information of the record, is found.

That means the analysis of the same record can be performed, presenting the three components, where different traces need to be indicated in each of the records for each component (*Record **1** = 0, Record **2** = 2, Record **3** = 4*). Now, a band-pass filter from 1 to 15 Hz is specified to display the images. The interface with the data entry will be as follows:

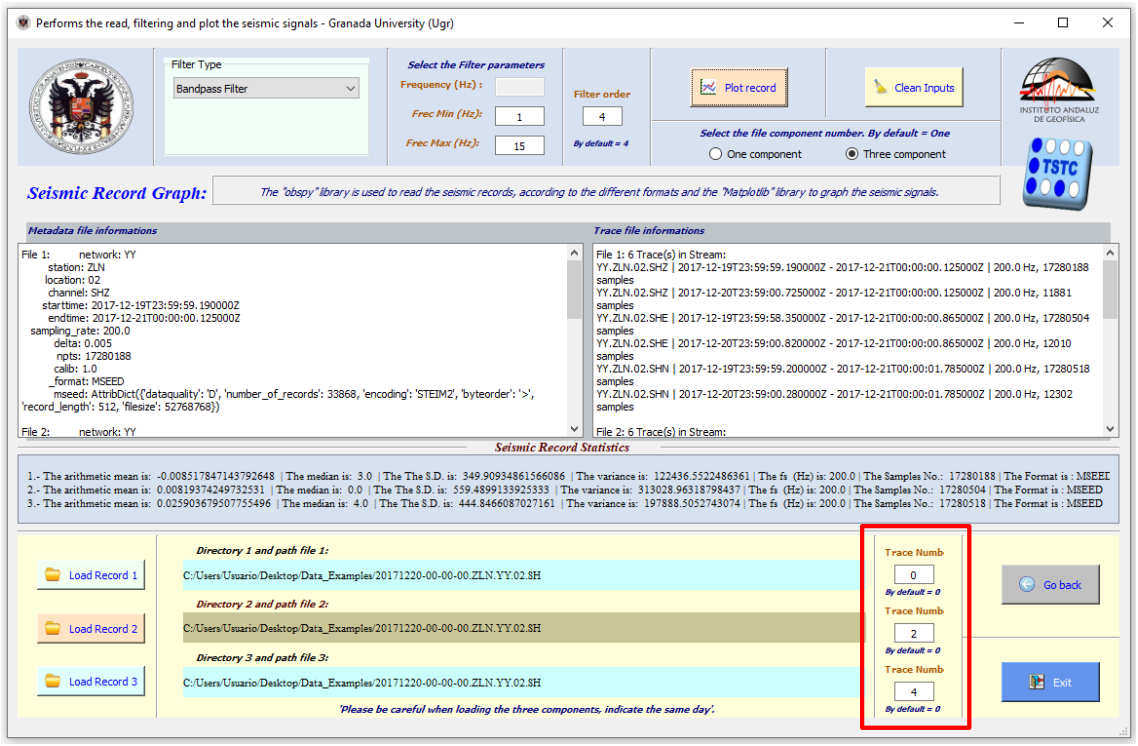


Fig. 29 Result of selecting a record with three components (*East-West, North-South, and Vertical*) that has different traces, using a band-pass filter from 1 to 15 Hz. The default values for filter order (4) are used, and the trace number is indicated for each component (*red box*): Record 1 = 0, Record 2 = 2, Record 3 = 4.

In this way, the resulting graphs from this analysis process are as follows.

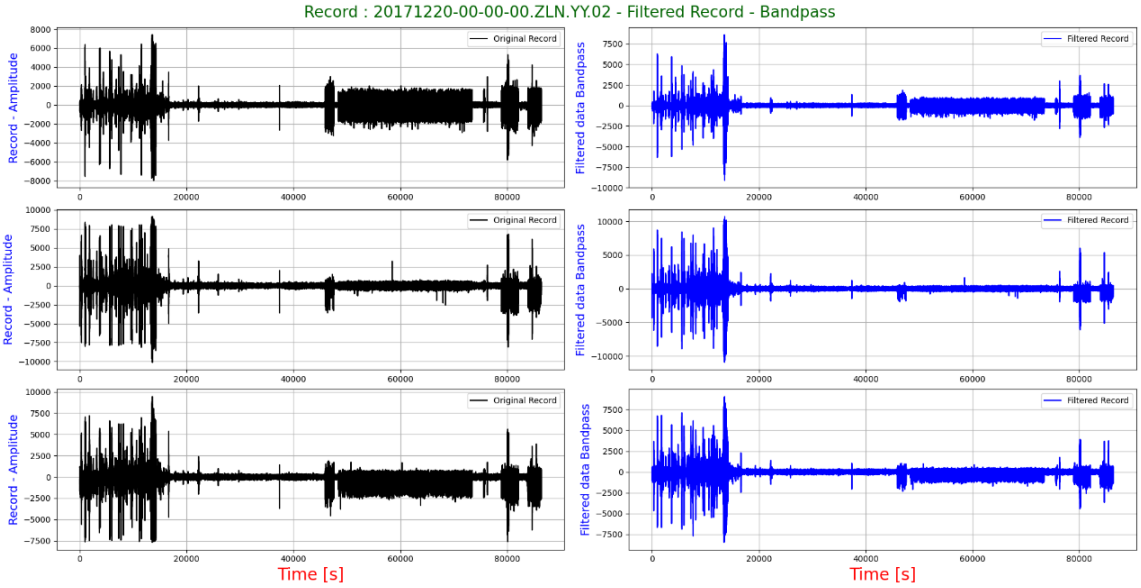


Fig. 30 Graph resulting from the previous process with three components and different traces, using a band-pass filter (1-15 Hz). On the left side, the original signals of each component, and on the right side, the filtered signals of each component.

To observe the resulting images in more detail, you can use the "*Magnifier*" tool (*zoom - see Section 6, point 5*), which will zoom in on the part of the graph that the user is most interested in, allowing for a detailed examination of the events present in the graphs. This can be seen in the following image.

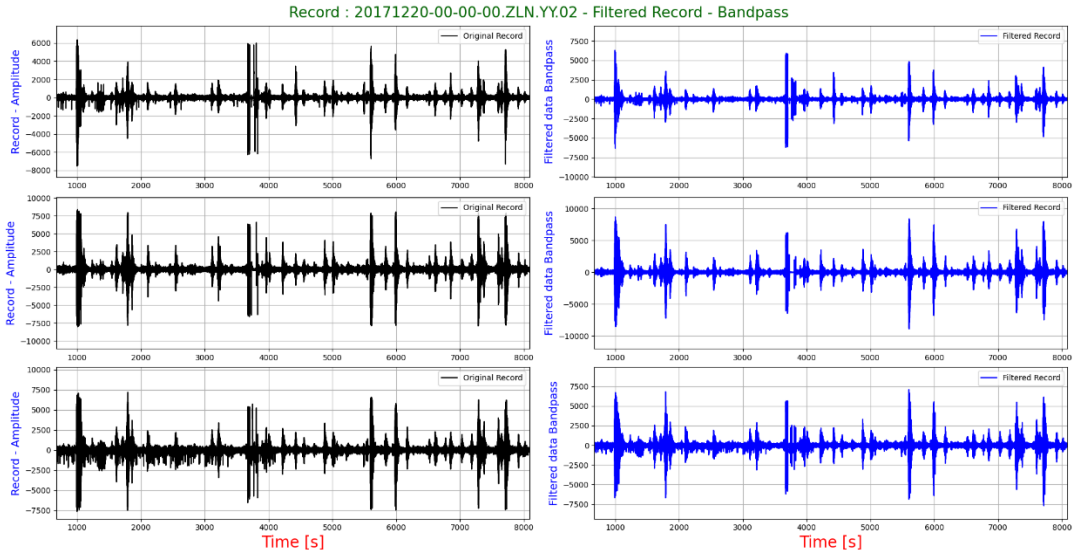


Fig. 31 ZOOM (*1000-8000 seconds*) of the previous graph (*Fig. 30*) resulting from the process with three components and various traces. On the left, the original signals of each component, and on the right, the filtered signals of each component.

To visualize in much greater detail, you can zoom in on a specific area. For example, the range between 5600 and 6200 seconds to observe the events. The result is as follows.

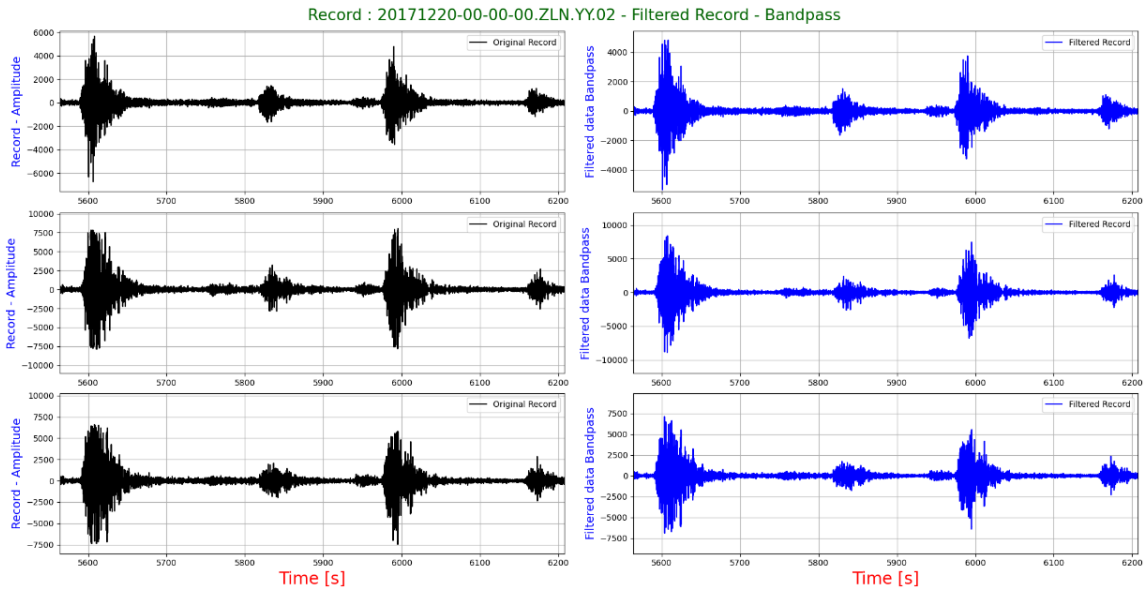


Fig. 32 Zoom (*5600-6200 seconds*) of the previous graph (*Fig. 30*) resulting from the process with three components and various traces. Left side shows the original signals of each component, and the right side shows the filtered signals of each component.

NOTE: When zooming in any area of an image, the remaining graphs automatically adjust, and the zoom of the three components is presented simultaneously.

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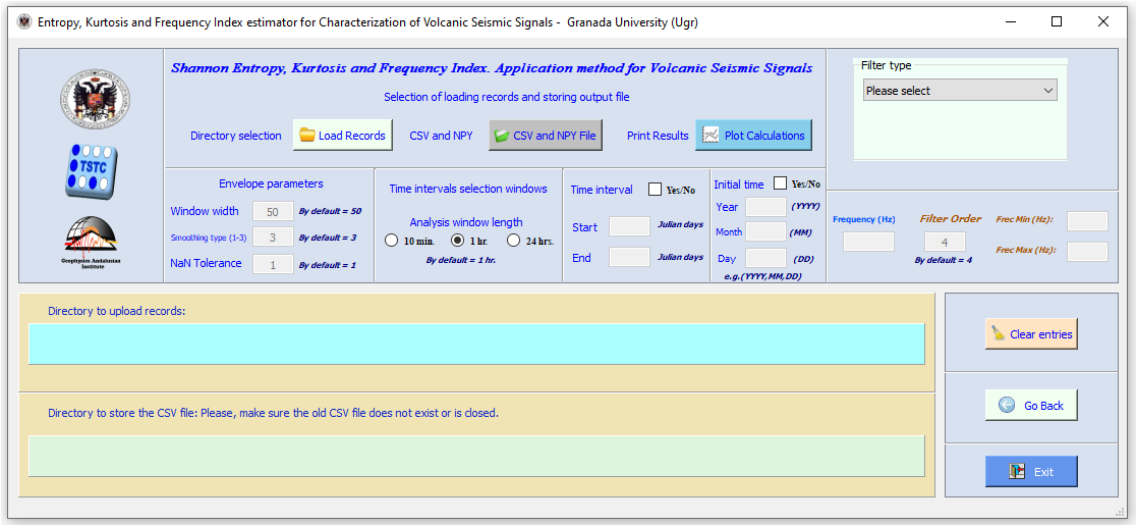
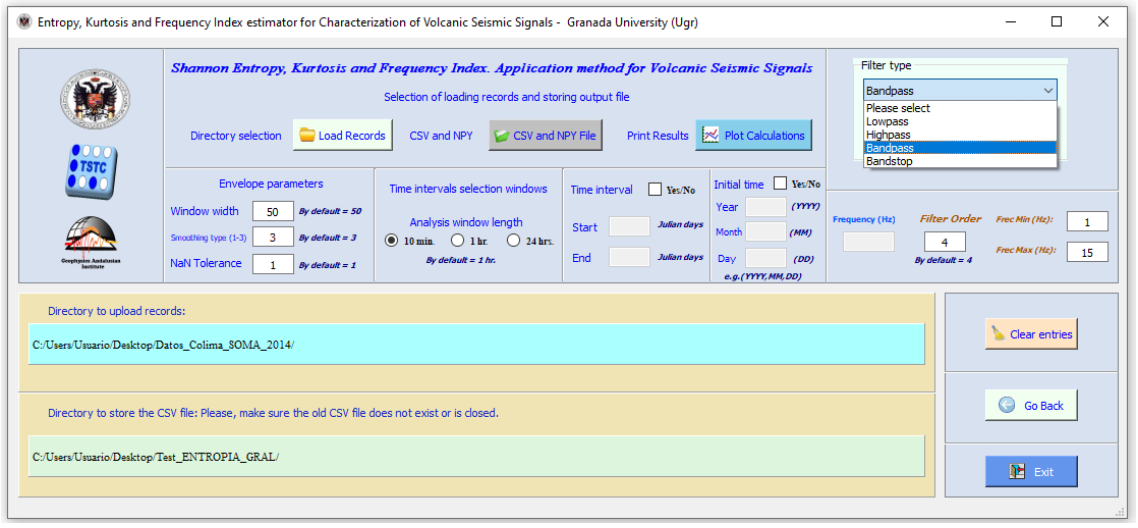
MODULE II

ENTROPY APPLICATION METHOD FOR SEISMIC-VOLCANIC SIGNALS





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4.- Shannon Entropy reading, calculation and graph module.

The module "*Entropy application method for Volcanic Seismic-signals*" (*Entropy1.py*), allows for the reading, calculation, and graphing of three analysis tools: a) Shannon Entropy, b) Kurtosis, and c) Frequency Index, along with their respective envelopes. The reading of records in various formats, filtering, and calculation results in six types of graphs from this process, which are:

1. *Graph of Shannon Entropy values represented by duration points.*
2. *Normalized entropy graph represented by duration points.*
3. *Graph of entropy with its envelope (calculated using a multidimensional median filter) represented by duration points. This calculation can be visualized in various ways by adjusting the envelope window size parameter.*
4. *Graph containing only the envelope line.*
5. *Graph of the frequency index with its envelope.*
6. *Kurtosis graph with its envelope.*

The objective of this second module is to read records contained in a folder for up to one year (365 or 366 records, depending on whether it is a leap year). The module allows for the selection of time intervals and, using filters, performs calculations with various analysis windows (*10 minutes, one hour, and 24 hours*), where each point represents the calculated value of the window. That is, points for: every 10 minutes, one hour, or 24 hours. Additionally, an envelope is applied. The envelope can assign different parameters: a) Window size: (*50, 100, 200, 300, 700, etc.*), b) Smoothing type (*1-3*), and c) Nan Tolerance (*1 by default*). The larger the envelope value, the greater the spacing of the envelope graph. Therefore, the user must decide which values to set to best represent the smoothness of the envelope. Additionally, two result files will be created and stored in a folder selected by the user. Additionally, two result files will be created and stored in a folder selected by the user.

1. **CSV File:** A Comma-Separated Values file where the data is stored in a tabular structure format, viewable in Excel. This file stores Shannon entropy and normalized entropy values, organized by days and hours within the selected interval or for the entire set of records (*001-365 in Julian days*).

2. **NPY File:** A NumPy matrix file containing an array where all the information is stored to reconstruct the array and graph the calculated Shannon entropy. Through a simple program, the graph of the calculated Shannon entropy can be reproduced instantly.

Important Note: *When calculating Shannon Entropy, the graphs may show points with very high or negative values (due to reading errors), resulting in graphs with elevated or negative peaks (Cf. Section 4.3.3). To avoid this, it is necessary to review the days to which these points correspond in the CSV results file and remove them from the database or the folder being analyzed. Afterward, the process should be repeated to ensure uniform resulting graphs.*

The interface of this module with its main elements is observed in the following image:

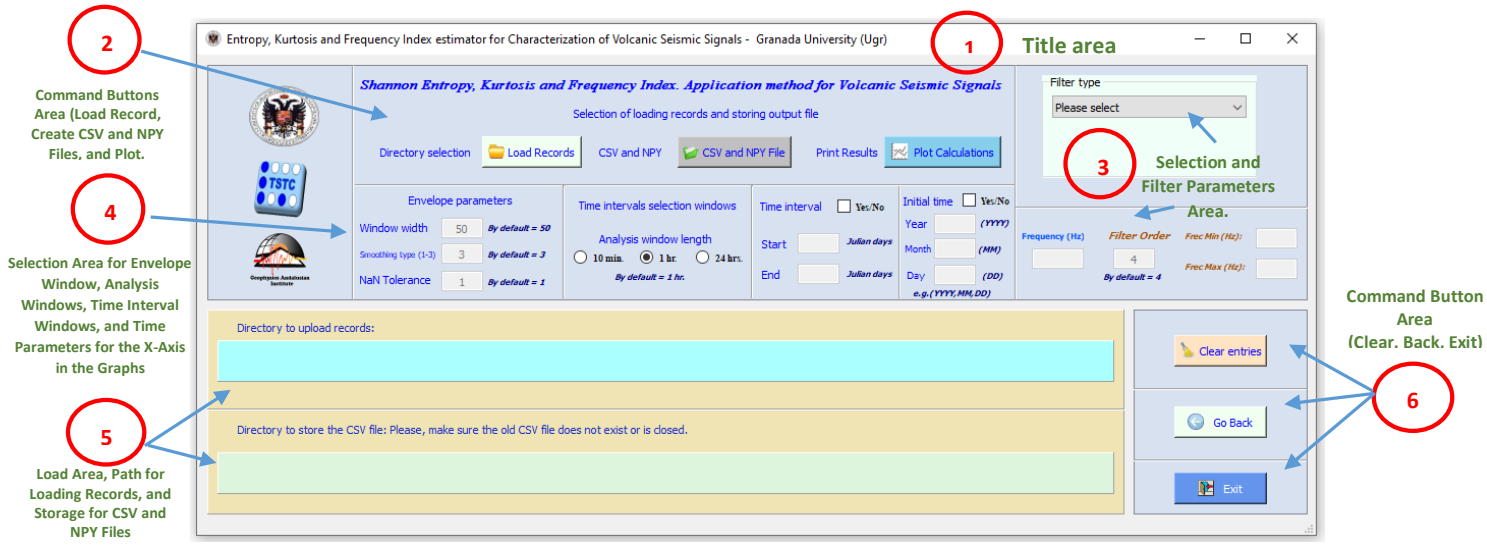


Fig. 33 Interface of the module for reading, filtering, calculating, and graphing Shannon entropy, along with its component elements

As seen in the above figure, the elements that compose this interface are as follows:

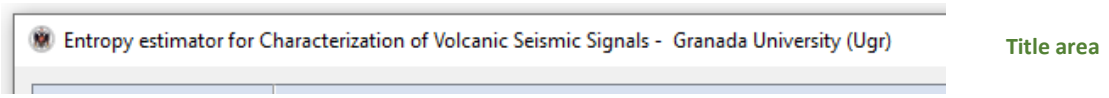
1) Title Area
2) Command Button Area: (Load record, create CSV and NPY files, and Plot Entropy)
3) Selection and Filter Parameters Area.
4) Parameters Selection Area:
    a. Envelope:
        i. Window Size: (50, 100, 200, 300, 700, etc.). By default, a window size of 50 is determined.
        ii. Smoothing Type (1-3). By default, a smoothing value of 3 is set.
        iii. Nan Tolerance (1 by default).
    b. Selection of analysis window size. Default value is 50.
    c. Selection of a specific time interval for analysis of the records (start - end). Set in Julian days.
    d. Set a time interval (year, month, day) for the x-axis in the resulting graphs. The format is in Gregorian calendar (YYYY, MM, DD).
5) Load Area or Path, where the records are located and where the resulting CSV and NPY files will be stored.
6) Command Button Area: Clear, Go Back, and Exit.

4.1.- Module Elements for Reading, Calculation, and Graphing of Shannon Entropy.

The elements that make up the main screen are detailed below.

4.1.1.- Title area. (1)

Located at the top of the module interface, Displays a information or identifier for the module. It includes the program name, icon, and university name as the title. (1).



In Addition to the title area (1), various elements of the interface are observed, numbered from (2-6) in the *red circles*. Each of these elements will be described below:

4.1.2.- Command Buttons Area: (Load record, create CSV and NPY files, and Plot Entropy) (2)

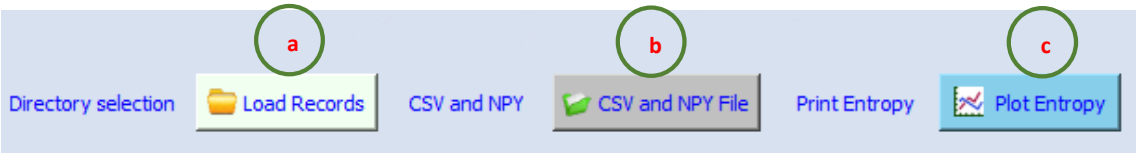
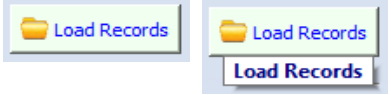


Fig. 34 Command Buttons area: (**a**) Load record, (**b**) create CSV and NPY files and (**c**) Plot Entropy

In the previous figure, the function of the command buttons that are observed is:

a) "*Load Record*" Button:
Functionality: Allows the user to load seismic records for analysis.
Loading the physical "*Path*" from the folder where the seismic records to be processed are located.
Appearance: Button labeled "Load record."
When the mouse pointer is placed over it, it displays the text indicating the action to be performed, which is "*Load Records*".



Clicking the button opens a Windows dialog box that allows the user to select the folder containing the records they want to work with. The dialog box looks similar to the following:

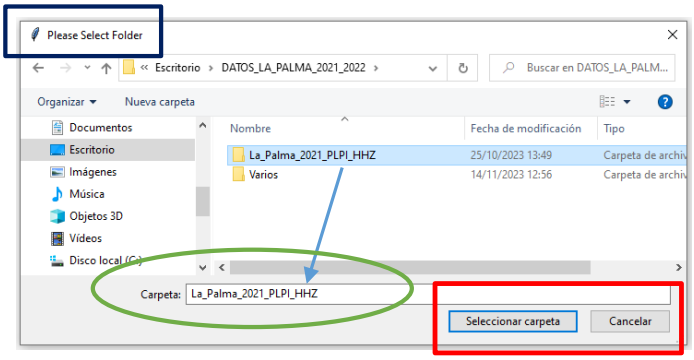
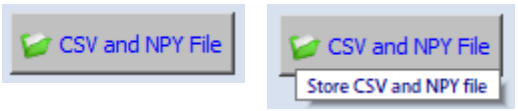


Fig. 35 Dialog Box for Selecting the Folder Where the Records are Located.

As shown in the image above, at the top (*blue box*), the user is instructed to select the folder to work with ("*Please Select Folder*"). At the bottom (*red box*), the two action buttons are visible, and once the folder is selected, they can be used ("*Select Folder*" and "*Cancel*"). By clicking "*Select Folder*," the name of the chosen folder, indicated by the arrow in blue, appears in the "*Folder*" area (*green ellipse*), and the **path** is displayed in the loading section (*See Section 4.1.5*). If you decide not to choose a folder, you can click the "*Cancel*" button, and the action continues in the main interface to select a new folder.

b) "CSV and NPY File" Command Button: Specifies the path of the selected folder by the user where the result files "*CSV*" and "*NPY*" will be stored.



Upon clicking the button, a Windows dialog box appears (*similar to the previous step*), allowing the user to select the folder where the resulting "*CSV*" and "*NPY*" files from the Shannon Entropy calculation process will be stored. The window is similar to Figure 35, indicating to select the folder. Just like in the previous step, the path is displayed in the loading section (*See Section 4.1.5*).

NOTA: **Importante**, debe de estar cerrado o no existir cualquier archivo CSV previo, de lo contrario se presentará un error.

c) "Plot Entropy" Command button: Upon clicking this button, the calculation is performed to obtain the four graphical results of Shannon Entropy and its envelope. Additionally, the resulting "*CSV*" and "*NPY*" files are saved in the selected folder.

NOTE: The following parameters must be entered beforehand:
a) Path, both for the data directory and the directory to save files (*CSV and NPY*),
b) The type of filter with its parameters, input parameters (*analysis window size and envelope*),
c) Activate and enter inputs, in case of performing an interval. Upon clicking the button, if there is any input error, a dialog box indicating the error is displayed (*See Section 4.2 - Validation Messages*), then the calculation of Shannon Entropy is performed, the four graphical results are presented, and the two resulting files are saved in the previously selected folder.

4.1.3.- Filter Selection and Parameter Area.

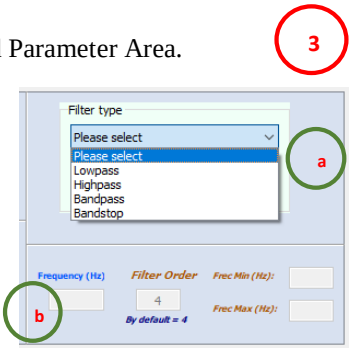
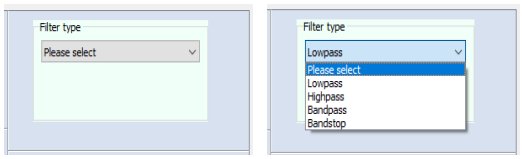


Fig. 36 Upper Part -> (**a**) Filter Type Selection (*Lowpass, Highpass, Bandpass, Bandstop*).
Lower Part -> (**b**) Filter Parameters (*Frequency, Filter Order, Minimum Frequency, Maximum Frequency*).

In the previous figure, marked with green circles, the two parts of this area are presented and defined as follows:

a) Filter Type Selection Area.



In the above image, the left part initially instructs the user to perform or select the type of filter they want to use. By clicking on this dropdown (*ComboBox*), the available filter options are presented, which are: (*Lowpass*[6]), (*Highpass*[7]), (*Bandpass*[8]) and (*Bandstop*[9]).

NOTE: By default, the command button for the calculation and presentation of Shannon entropy results (*Plot Entropy*) is disabled. This button is activated once the user has selected the filter type.

b) Filter Parameter Selection and Entry Area.

Fig. 37 Filter Parameter Selection Area: (**1**) Frequency Parameter (Hz), (**2**) Filter Order Parameter (*default = 4*), (**3**) Minimum and Maximum Frequency Parameters (Hz).

1) Frequency Parameter (Hz): This box is activated when selecting low-pass (*Lowpass*) and high-pass (*Highpass*) filter types. In this selection, the minimum and maximum frequency boxes remain deactivated. Entries in this box are validated to allow decimal numbers.

---

[6] **Lowpass Filter:** The lowpass filter blocks high-frequency signals and allows low-frequency signals to pass through (*frequencies lower than the cutoff frequency*).

[7] **Highpass Filter:** The highpass filter blocks low-frequency signals and allows high-frequency signals to pass through (frequencies higher than the cutoff frequency).

[8] **Bandpass Filter:** The bandpass filter allows spectral content only in the vicinity of the central frequency. This window is created through a minimum frequency value and a maximum frequency value. It eliminates noise associated with low and high frequencies generated and/or residual.

[9] **Bandstop Filter:** The bandstop filter does not allow the passage of signals whose frequencies are between the upper and lower cutoff frequencies. In other words, it eliminates frequencies or stops a particular frequency band.

2) Filter Order Parameter: By default, this parameter is set to a value of four (4) at the beginning. This input box is activated when selecting any of the four available filter types. It allows the user to enter a different (*valid*) filter order value (*2, 6, 8, 12, etc.*). The entry in this box is validated to accept only two-digit integers.

3) Minimum and Maximum Frequency Parameters (Hz): These two text boxes are activated when selecting the filter types; Bandpass and Bandstop. In this selection, the Frequency (Hz) input box is deactivated. The entries in these two boxes are validated to allow decimal numbers.

NOTE: *In the image above, all data entry boxes shown are initially deactivated by default. They are also validated to only accept numerical input and not alphabetic characters or letters. The values to be entered in these boxes will be centered in the text boxes.*

4.1.4.- Selection area of: intervals, analysis windows, and envelope window.

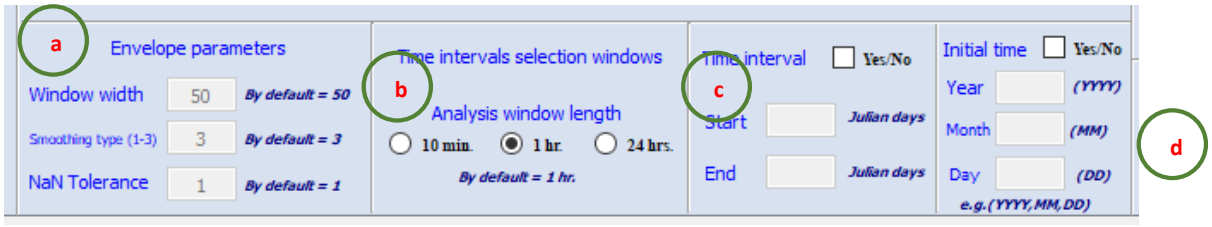
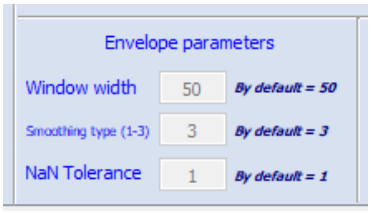


Fig. 38 Selection Area for Intervals, Analysis Windows, and Envelope Window: (**a**) Selection of envelope parameters (**b**) Selection of analysis window size (*10 minutes, 1 hour, and 24 hours, default is set to 1 hour*). (**c**) Selection of time interval. These text boxes are disabled; by checking the box (*Yes/No*), it indicates whether a time interval is desired ("*YES*"), default is blank indicating "*NO*" (Input the initial day and final day desired in Julian days). (**d**) Selection of the initial time interval to be represented on the x-axis (*indicated in Gregorian days with format YYYY, MM, DD*).

In the image above, marked with green circles, the four sections (*a-d*) that make up this area are observed.

a) Envelope Parameter Selection:



In this box, the user inputs the values for envelope parameters, indicated in three entries:

i. Window Size (default is set to 50),
ii. Smoothing Type (default is set to 3),
iii. NaN Tolerance (default is set to 1).

NOTE: *When the user selects the data folder to work with, the number of data points is included, even if the number of records is less than 365. This only indicates the maximum number of data points to be used. If you wish to work with a smaller number, for example, a month, the easiest and most viable option is to use the time interval and specify it in section (c), leaving this value by default to represent the maximum size to be analyzed.*

An example of analysis with various window sizes to observe the smoothing of the envelope is shown in Figure 41.

b) Selection of the analysis window.

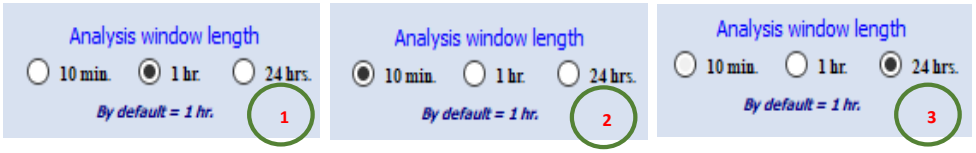


Fig. 39 In this area, the user indicates the size of the analysis window: (**1**) 10-minute window, (**2**) 1-hour window, and (**3**) 24-hour window.

In this box, the user selects the analysis window desired for applying to the data: (*10 minutes, 1 hour, and 24 hours*). The default entry in this box is set to one hour. The user can select any of the window sizes at the beginning by clicking on the indicated area. As shown in the image above, the user at point (**1**) has selected to work with one-hour windows or the default value, at point (**2**) with 10-minute windows, and at point (**3**) with 24-hour windows. The validation of this section indicates that by clicking on a specific value, that point is selected, and the other two remaining points are deactivated.

c) Time interval selection.

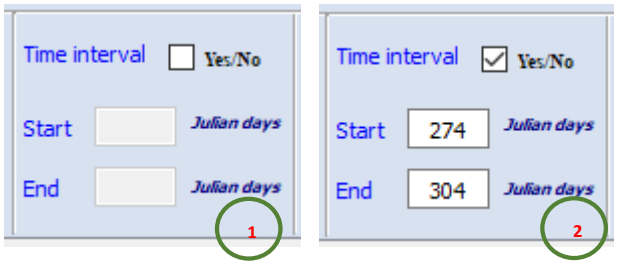
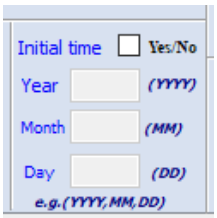


Fig. 40 The figure shows the box where the user determines whether a time interval will be used to analyze the data: (**1**) Initial position, an empty value in the "Yes/NO" box, indicating a "*NO*" value (**2**) The "Yes/NO" box is checked, indicating a "*YES*" value, activating the "Start" and "End" text boxes to enter dates in Julian days.

In the box above, it can be observed that part (**1**) is set with the default initial values, meaning it is not selected, indicating that the time interval is **NOT** desired, and the text boxes indicating date entries (*Start and End*) in Julian days are deactivated. In part (**2**), the "*Yes/No*" box has been selected or marked, indicating that YES, the time interval is desired. To do this, the user must also select the filter type, which activates the text boxes for start (Start) and end (End) dates, expressed in Julian days. In the example shown in the figure, the start and end dates are entered as values (*274-304*) respectively, meaning that the records for the month of "*October*" in a non-leap year (*2014, 2015, 2017, 2019, 2021, 2023, etc.*) will be analyzed. Data entry in these boxes is validated to accept only valid integer numbers (*three digits*), centered in the box.

d) Envelope window size selection.

The box on the right indicates the size of the envelope window (*calculated using a multidimensional median filter*) for the calculation. By default, its value is set to 50. However, the user can assign the desired value. An example of the comparison of graphs, showing the envelope values for various sizes, is shown in the figure on the following page.



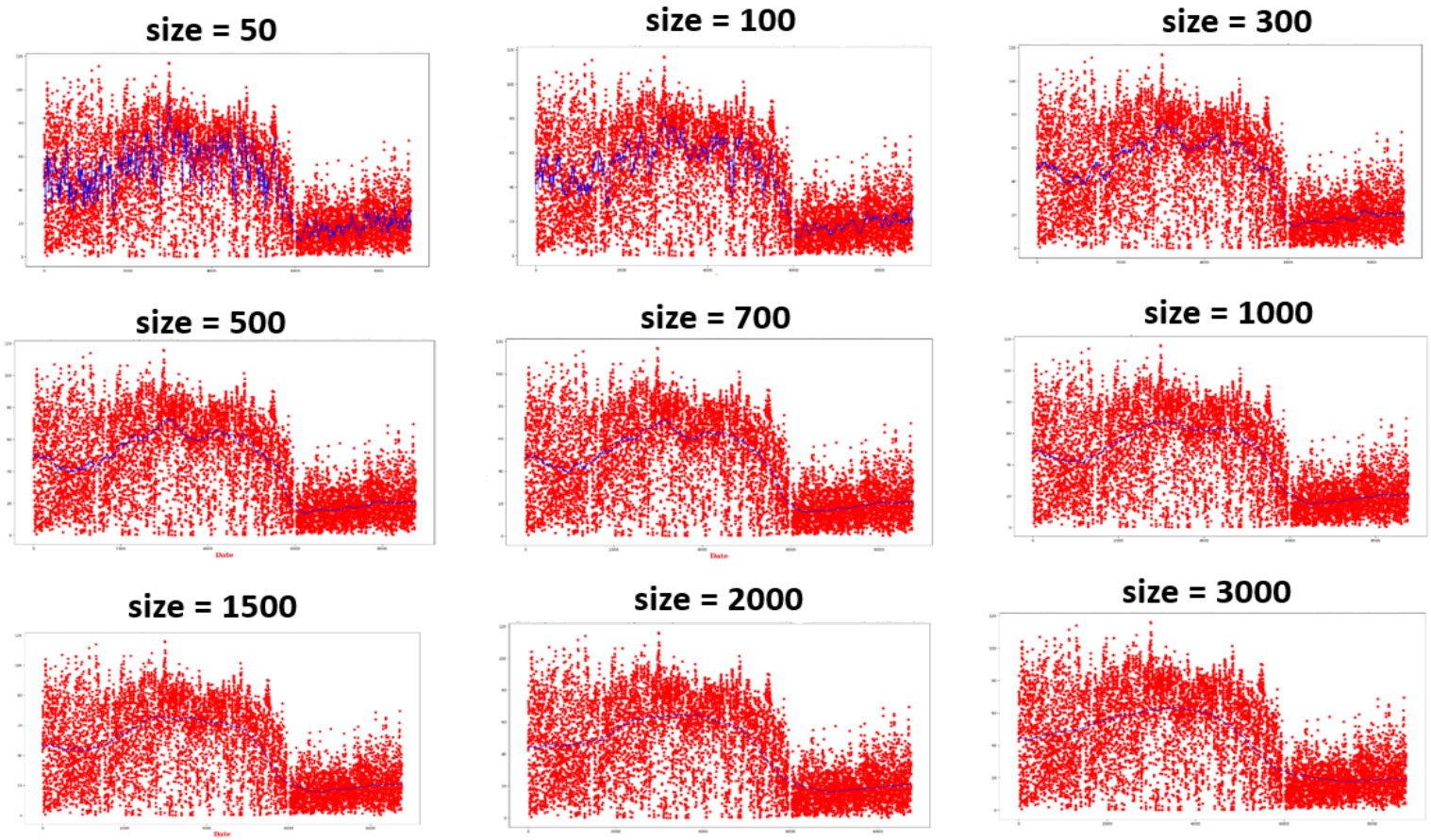


Fig. 41 Example of a comparative graph over a year of records, showing various envelope window sizes such as: (***50, 100, 300, 500, 700, 1000, 1500, 2000 y 3000***).

In the previous figure, the results for a year of records are presented, showing that the envelope line becomes smoother with a larger window size. However, the user must assess and decide which size to use based on the expected results. A larger window size significantly smoothes the slope of the envelope but may also result in various peaks or jumps in the envelope at different parts of the signal, depending on the number of records present in a given year.

4.1.5.- Path Area (*Directory or Folder*)

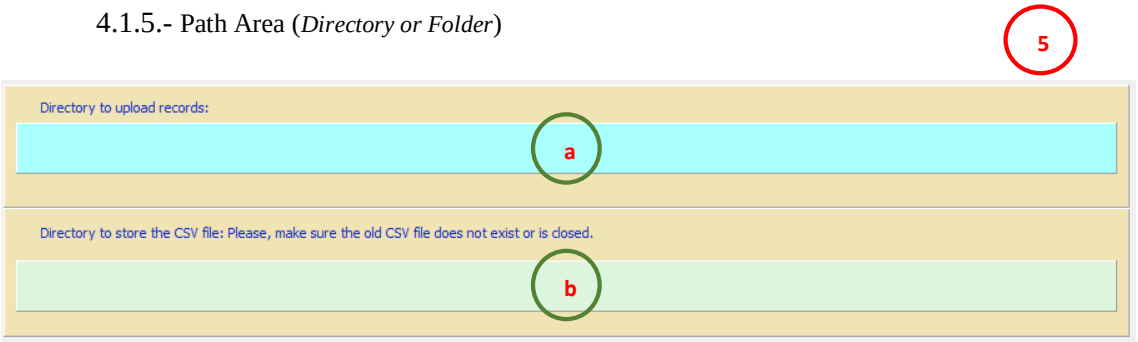


Fig. 42 The area where the directories or folders for the actions of the command buttons "*Load Records*" (**a**) and "*CSV and NPY File*" will be displayed (**b**).

In the image above, the two areas where the directory paths will be visualized for the actions of the command buttons "*Load Records*" and "*CSV and NPY File*" are shown, as described in section 4.1.2.

a) Path Area (***Directory or Folder***): The area where the path or directory containing the records to be processed will be displayed.
b) Path Area (***Directory or Folder***): The area where the path or directory where the "*CSV*" and "*NPY*" result files will be stored or saved will be displayed.

NOTE 1: It is important that there are no existing CSV files; otherwise, an error will occur.
NOTE 2: It is crucial that these two areas are defined before clicking or executing the "Plot Entropy" command button (see Section 4.2, point (c)), which performs the calculation, printing, and results of Shannon Entropy and its envelope. Otherwise, data validation dialog boxes will appear (*see section 4.2*).

4.1.6.- Command Buttons Area: (Clean, Go Back, and Exit).

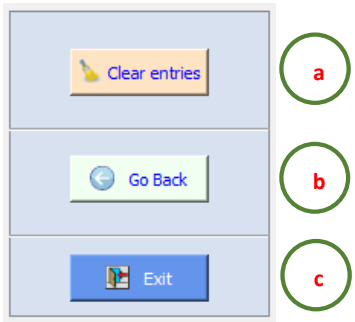


Fig. 43 Command buttons area: (**a**) Clear entries, (**b**) Go Back and (**c**) Exit.

In the figure above, the functions of the observed command buttons are:

a) "Clean entries" command button: This button clears or erases the input elements, closes existing charts, and resets the analysis screen to its initial state, ready for a new search and calculation of Shannon Entropy with seismic events. (*The text displayed when hovering over the button is shown*).

A validation is introduced when executing this button to prevent accidental deletion of user-input parameters. Clicking this button prompts a dialog box asking the user if they really want to delete the entries. The dialog box looks like the following:

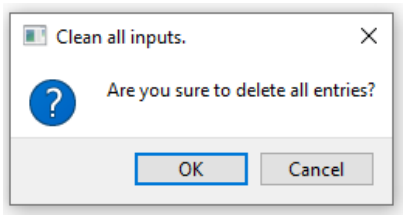
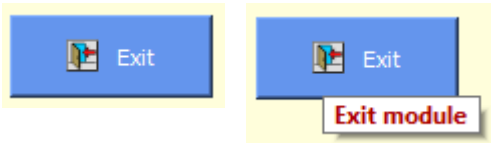


Fig. 44 Verification Dialog Box for User-Initiated Entry Deletion.

As seen in the figure, if the user indeed wants to delete the entries, they click the "OK" button, and all entries will be removed. The interface screen of the module will then present the initial values with the checkboxes deactivated. If, on the other hand, the user pressed the cleanup button by mistake or does not want to proceed, they click the "Cancel" button, and the execution returns to the interface screen.

b) "Go Back" command button: This button allows the user to return to the initial presentation screen of the system (*main menu*). Hovering the mouse pointer over it displays a message indicating its function.

c) "Exit" command button: This button enables the complete exit from the module and the system (*following the presentation of a screen asking if the user wants to leave the module and the system*). Hovering the mouse pointer over it displays a message indicating its function.



Similarly to the startup screen, if the "*Exit*" command button is pressed or clicked, a window appears asking the user if they are sure about leaving the module and the system. This window looks like the following:

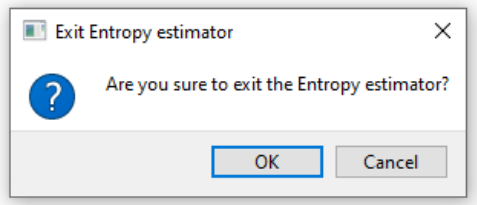


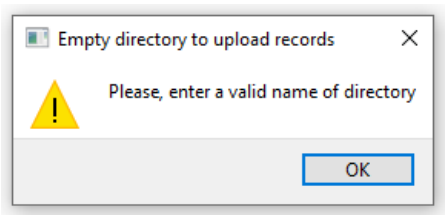
Fig. 45 Text box indicating whether you want to exit the module and system.

On clicking "OK," the screen closes, and the module and system exit is completed. Clicking "Cancel" will continue on the Shannon Entropy calculation screen.

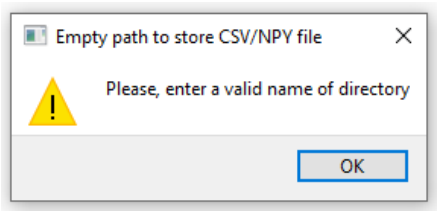
4.2.- Validation of Errors in Record or Entries.

In the event of attempting to calculate and plot Shannon Entropy by clicking the "Plot Entropy" button without entering data in any of the required input boxes or text fields, a validation will occur. This will display a dialog box indicating that this action needs to be performed, and input errors should be corrected. Additionally, these dialog boxes allow the program execution to proceed without severe interruption of the system due to data absence. The validations for incorrect inputs include:

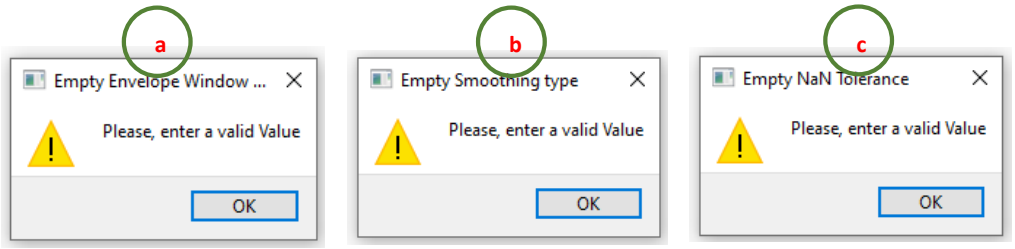
a) Validation for data entry - Records directory empty.



b) Validation for data entry - "CSV" and "NPY" File directories empty.



c) Validation for data entry – Envelope Parameters.

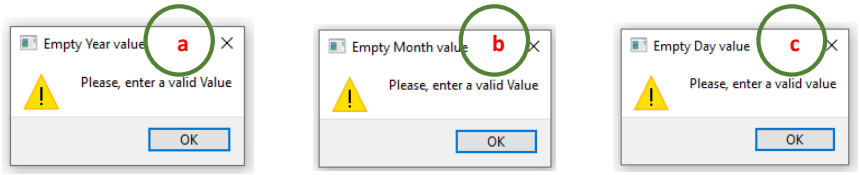


(a) Empty Envelope Size Value. **(b)** Empty smoothing value. **(c)** NaN Tolerance at empty value.

d) Validation for data entry – Empty initial and final time interval.

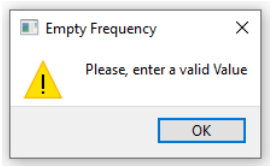
(a) Empty initial time interval value. (b) Empty End time interval value.

e) Validation for data entry – Initial time interval for the x-axis.

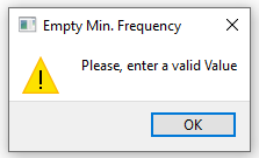


(a) Emply year value. (b) Empty month value. (c) Empty day value.

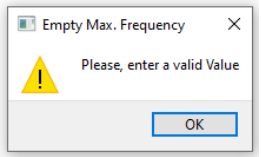
f) Validation for data entry – Empty Frequency value.



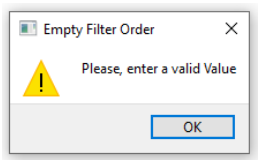
g) Validation for data entry – Empty Minimum Frequency value.



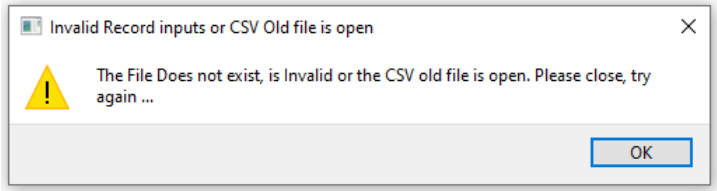
h) Validation for data entry – Empty Maximum Frequency value.



i) Validation for data entry – Empty Filter Order Value.



j) Validation in case of encountering a different input error than the ones mentioned earlier, such as a non-existent, invalid file or CSV file open.



According to the message in the above figure, an error has occurred because the format is invalid, the record does not exist, or the previous CSV file is open. Additionally, parameters or entries may be outside the allowed range according to the signal to be analyzed. Clicking the "*OK*" button returns to the system to choose a valid file or correct erroneous entries or close the CSV file and repeat the process. This allows the program to continue executing without troubles.

4.3.- Execution Process and Results of the Shannon Entropy Reading, Calculation, and Graphing Module.

The process to load records, filter, and graph Shannon Entropy (original and normalized) and its envelope is straightforward and involves the following steps (*it's recommended to follow these steps*):

a) Select the directory where the records are located by clicking the "*Load Record*" command button. Once selected, click the "*Open*" command button (*the file path is displayed in the "Directory to Upload Records" area - See 4.1.5*).
b) Select the directory where the result files "CSV" and "NPY" will be stored by clicking the "*CSV and NPY File" command button.* Once selected, click the "Open" command button (*the file path is displayed in the "Directory to Store the CSV File" area - See 4.1.5*). Remember, **not** to have a similar CSV file open simultaneously.
c) Select the filter type (*Lowpass, Highpass, Bandpass, or Bandstop*). This will activate the parameter input boxes based on the indicated selection.
d) Select the analysis window size (*default is one hour*).
e) Select the Envelope parameters or leave the default value = (50, 3, 1).
f) (**OPTIONAL**) Select or check the box (if required) to analyze a specific time interval. If positive, enter the start time in Julian days in the "Start" box and the end time in Julian days in the "End" box.
g) Enter the filter parameter values according to the selected type. For lowpass and highpass filters, enter a valid "frequency" value. For bandpass and bandstop filters, enter valid values for "*minimum frequency*" and "*maximum frequency*".
h) Enter (*if required*) the filter order or leave the default value = 4.
i) (**OPCIONAL**) Select or check the box (if required) to choose a specific initial time interval (Year, month, day) for values on the x-axis. If positive, indicate in the boxes: "YYYY, MM, DD" the start time in Gregorian days.
j) Finally, click the "Plot Entropy" button to calculate Shannon Entropy, display the four graphs, and store the two resulting files in the designated folder.

As indicated in the last step, once the above steps have been completed, click on the "Plot record" button. The output of this process will consist of the six graphs (*Shannon Entropy, Normalized Shannon Entropy, Shannon Entropy with envelope, Envelope-only graph, Frequency Index with envelope, and Kurtosis with envelope*). When the graphs are presented, you can zoom in (using the "Magnifying Glass (point 5)" tool - Refer to Section 6), on any part of them to observe the entropy's progression over time in much greater detail. The resulting files (CSV and NPY) can be found in the folder previously selected by the user for storage.

4.3.1.- Example of Shannon Entropy Calculation Procedure with a 1-hour Analysis Window.

As an example, the following process of the interface with output elements is presented for an analysis of Shannon Entropy and its envelope with a default 1-hour analysis window. In other words, each point corresponds to one hour.

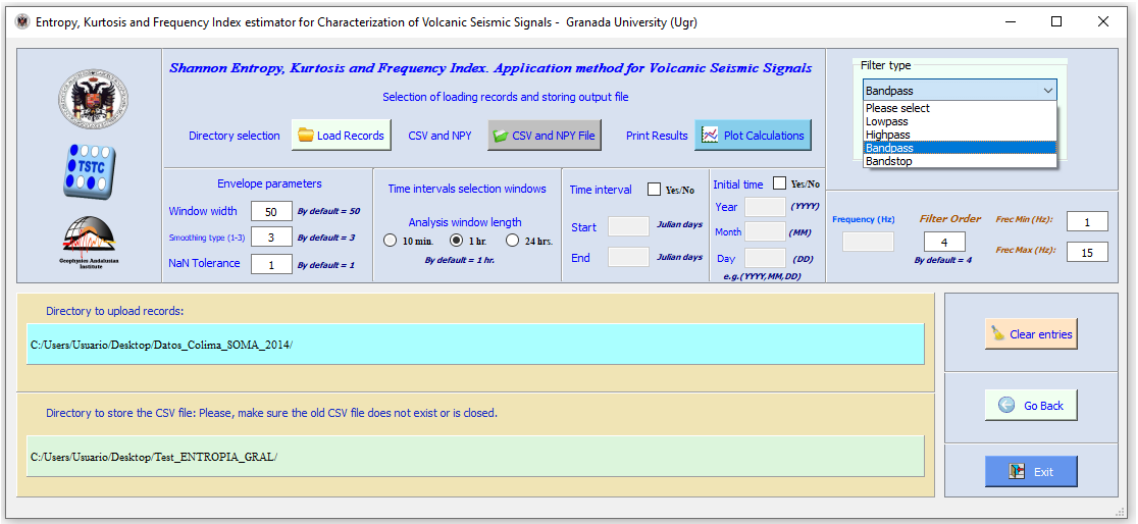


Fig. 46 Interface of the Shannon Entropy, Kurtosis, Frequency Index calculation module, and their envelopes, with the selected data for a one-hour analysis window, envelope window size of 50, smoothing type 3, Nan Tolerance with the default value = 1, and assigning a band-pass filter from 1 to 15 Hz.

In the above figure, the obtained values when loading one year's worth of records are observed (*the interval time field is not used*). The input parameters used are:

a) Envelope parameters (Default values: 50, 3, 1).
b) Analysis window to use = one hour (*Default value*).
c) Time interval (Not designated).
d) Filter type = Bandpass (*1 – 15 Hz*).
e) Filter order. The default value is used = 4.

As observed, the process is extremely simple. Here, the user only had to specify:

1) The folder where the data is located,
2) The folder where the two result files will be stored,
3) The filter type, and
4) The filter parameters.

* he remaining input values are the default ones.

Next, click on the "Plot Entropy" button, and the calculation and presentation of results are carried out. The six result graphs (with a Zoom included between points 5000 and 6200) obtained from this procedure are shown on the following page and are as follows:

a) **Left**: Shannon Entropy Calculation Graph. **Right**: Zoom into a specific area (*5000 to 6200 points*).

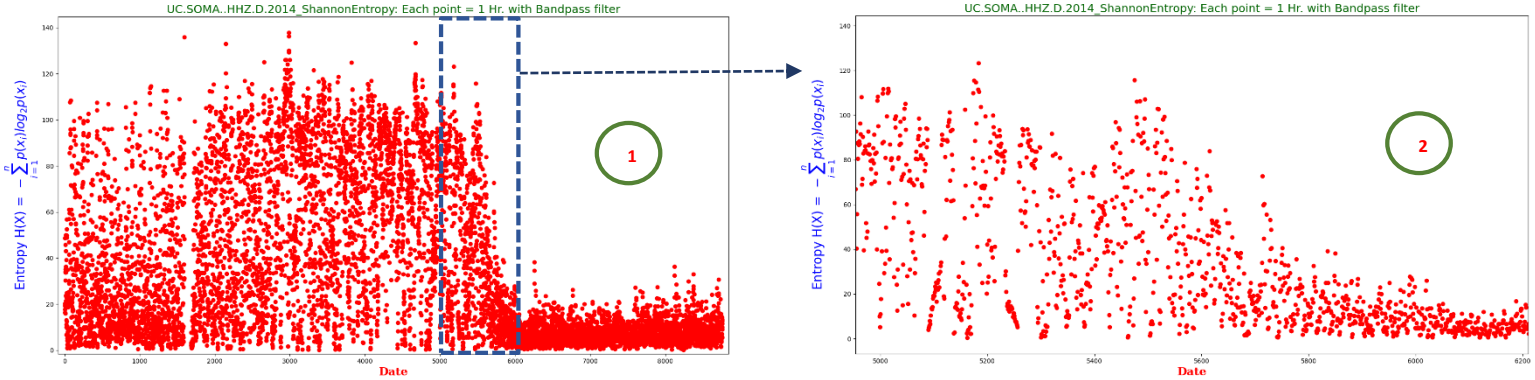


Fig. 47 (**1**) Graph of the Shannon Entropy calculation results. (**2**) Zoom into the area highlighted in blue, covering a range of 5000 to 6200 points.

b) **Left**: Normalized Shannon Entropy Calculation Graph. **Right**: Zoom into a specific area (*5000 to 6200 points*).

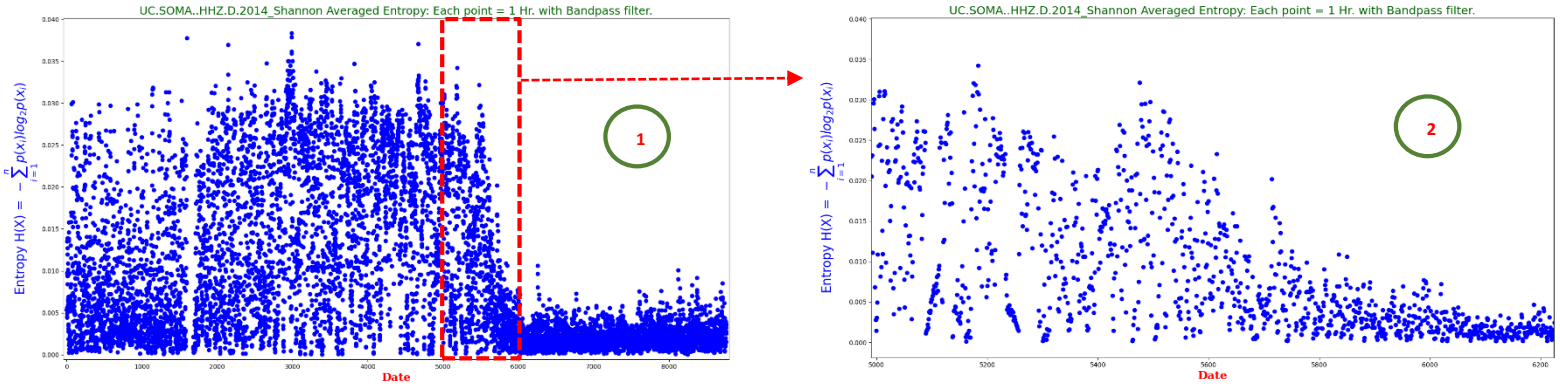


Fig. 48 (**1**) Graph of the results of the Normalized Shannon Entropy calculation. (**2**) Zoom into the area highlighted in red, covering a range of 5000 to 6200 points.

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c) **Left**: Graph of Shannon Entropy Calculation and its Envelope. **Right**: Zoom into a specific area (*5000 to 6200 points*).
The peaks present are mostly determined by seismic swarms.

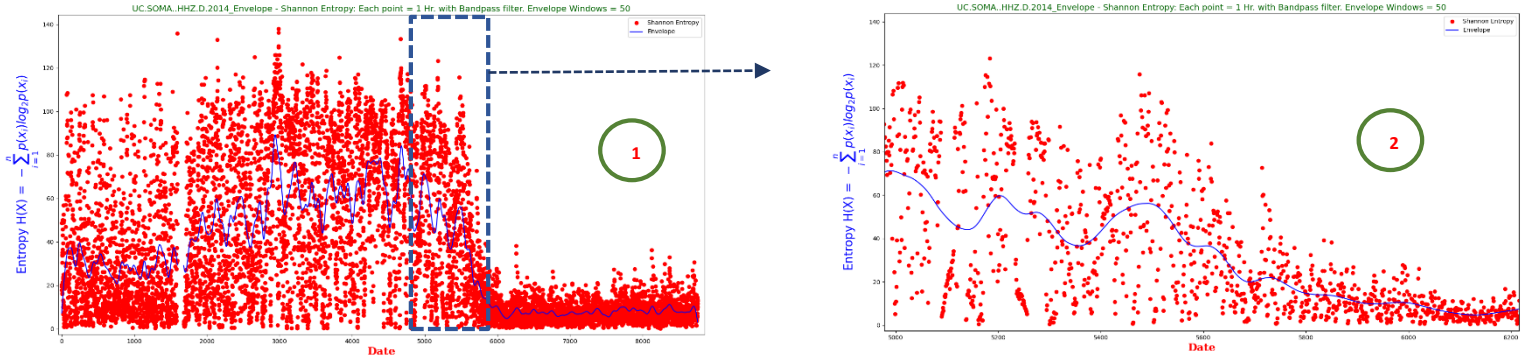

Fig. 49 (**1**) Graph of the results of Shannon Entropy calculation and its envelope. (**2**) Zoom into the area highlighted in blue, covering a range of 5000 to 6200 points.

d) **Left**: Graph of the representation of only the envelope of Shannon Entropy. **Right**: Zoom into a specific area (*5000 to 6200 points*).

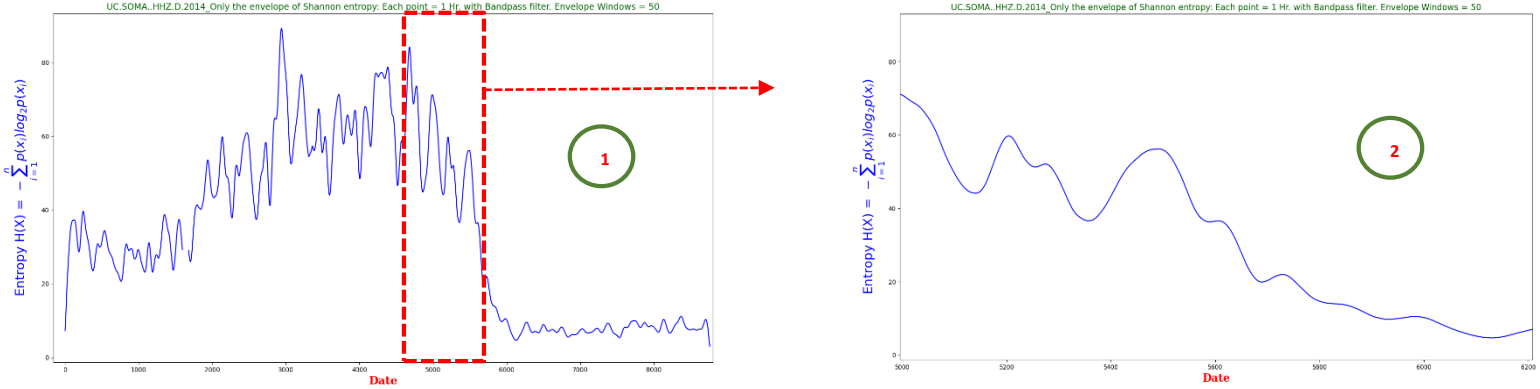

Fig. 50 (**1**) Graph of the results of Shannon Entropy calculation and its envelope. (**2**) Zoom into the area highlighted in red, covering a range of 5000 to 6200 points.

e) Left: Graph of the Frequency Index calculation and its envelope. Right: Zoomed-in view of a specific area (points 5000 to 6200). The peaks observed are largely determined by seismic swarms.

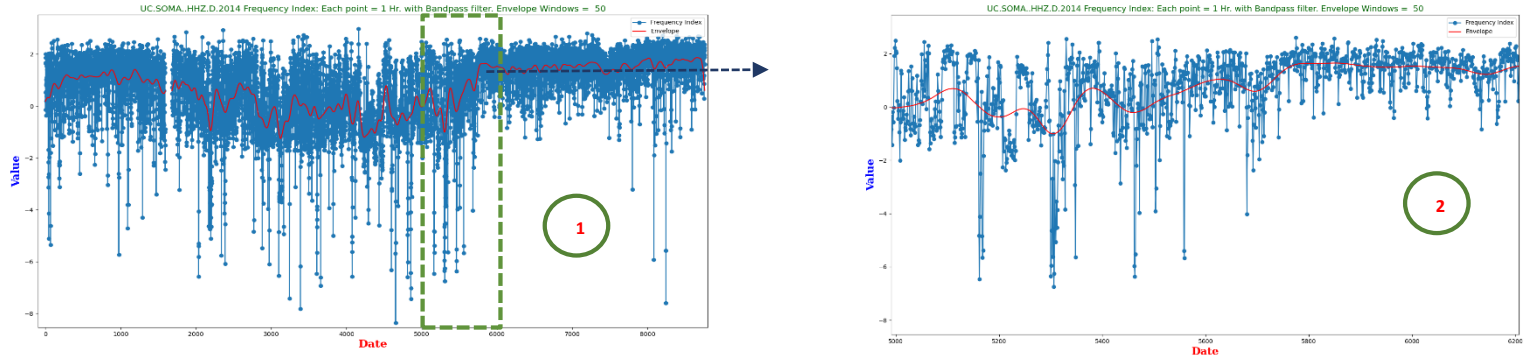

Fig. 51 (**1**) Graph of the results of Frequency index and its envelope (**2**) Zoom into the area highlighted in green, covering a range of 5000 to 6200 points.

f) Left: Graph showing the representation of Kurtosis with its envelope. Right: Zoomed-in view of a specific area (points 5000 to 6200).

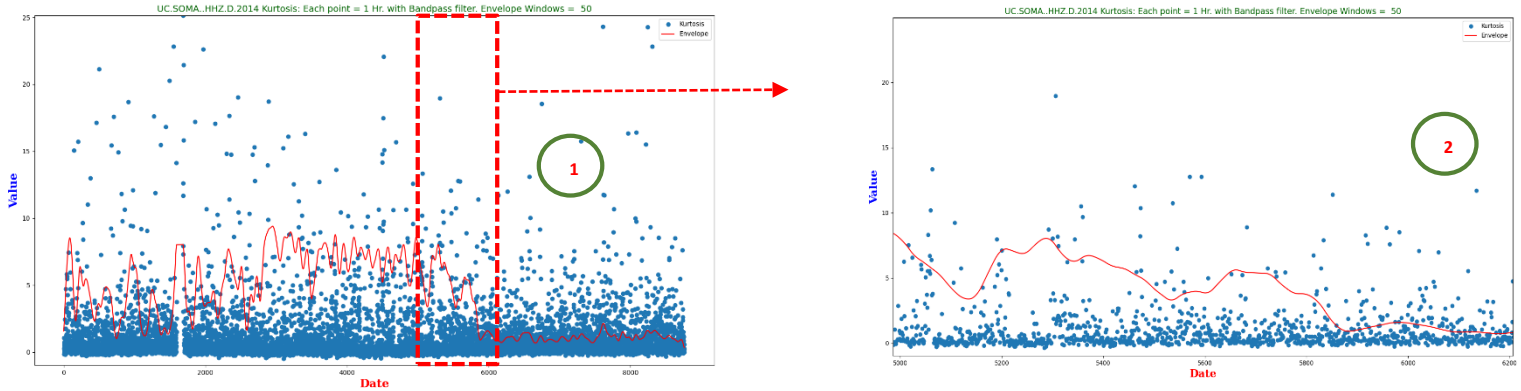

Fig. 52 (**1**)) Graph of the results of Kurtosis and its envelope (**2**) Zoom into the area highlighted in red, covering a range of 5000 to 6200 points

The previous figures (*47 to 52*) represent the graphical output of an example of Shannon Entropy calculation with one year of records, using one-hour analysis windows. Analyses can be performed using 10-minute, 1-hour, and 24-hour analysis windows with the four available filters (*Lowpass, Highpass, Bandpass, and Bandstop*). A comparison of this analysis is observed at the end of the document (*See Fig. 59 Page 47*). Similarly, calculations can be performed using analysis intervals (*for example, a one-month duration, See Section 4.1.4 point c*), using the same parameters previously indicated (*analysis windows and filter types*).

4.3.2.- CSV and NPY Result Files Stored in the User-Designated Folder.

The calculation process of the module also provides two result files, obtained through the calculation of Shannon Entropy and stored in the folder designated by the user for this purpose. These files represent:

a) CSV File (*comma-separated*), which can be opened and viewed in an Excel spreadsheet. The total points for 365 days are 8760 (*calculated in Excel*). An example of this file and its contents is presented in the following table (*The table shows points 1 to 24, corresponding to the month of January*).

The column within braces is a value obtained from an Excel formula (=A1+1) and copied throughout the column from the second value to the last of the 365 days. This way, each point from 1 to 8760 is obtained. They correspond to 24 points for each day, one point for each hour.

	day,hour,ShannonEntropy,ShannonAveragedEntropy
1	1,0,19.2425925385357 42,0.0053451645940377065
2	1,1,48.599766085210646,0.013499935023669625
3	1,2,17.771415781754314,0.0049365043838 20642
4	1,3,20.33907819990658,0.005649743944418494
5	1,4,16.388535923103717,0.0045523710897510325
6	1,5,16.048066879367568,0.00445779635537988
7	1,6,35.05629693399813,0.009737860259443924
8	1,7,34.09144537157257,0.009469845936547936
9	1,8,33.796642741378946,0.009387956317049707
10	1,9,30.338870637390666,0.008427464065941852
11	1,10,45.826932390056356,0.012729703441682321
12	1,11,43.05404981588691,0.01195945828219081
13	1,12,49.96734888704295,0.01387981913528971
14	1,13,36.40665227252762,0.0101129589645910 06
15	1,14,33.88328344223024,0.009412023178397289
16	1,15,21.430653538882 48,0.005952959316356245
17	1,16,23.762730167393677,0.006600758379831577
18	1,17,39.283523526623 53,0.010912089868506537
19	1,18,23.004567281315932,0.006390157578143314
20	1,19,13.07593141541339,0.0036322031709481637
21	1,20,6.6917577191751105,0.001858821588659753
22	1,21,9.946347158747585,0.002762874210763218
23	1,22,11.2045520534347,0.0031123755703985276
24	1,23,12.432288855412256,0.003453413570947849

Tabla 2. Example of the "CSV" results file obtained through the Shannon Entropy calculation process. The information (*Days, hours, Shannon Entropy value, Normalized Shannon Entropy value*) is separated by commas. The example indicates the values for day one, from hour 0 to 23 (*corresponding to points 1 to 24*). The total value of the CSV file includes 365 days analyzed. Here, each point corresponds to a one-hour analysis window.

Important Note: When calculating Shannon Entropy, the graphs may contain points with very high or negative values (*due to reading errors*), which will result in a graph with elevated or negative peaks. To avoid this, review which days correspond to those points in the CSV results file and remove them from the database or the folder where the analysis is performed. Then, repeat the process to ensure uniform resulting graphs (*See next section 4.3.3*).

b) File "NPY" (*NumPy array file containing an array where all information of type and shape is stored to reconstruct the array and graph the signal instantly through a simple program*), from which, the calculated Shannon Entropy graph can be reproduced without redoing the entire process.

4.3.3.- Points with very high or negative values in the graphs of Shannon Entropy calculation.

Sometimes, the resulting graph may contain very high or negative values in the calculation of entropy. This could be due to segments with errors in storing data in the sensor. This can be observed in the following figures.

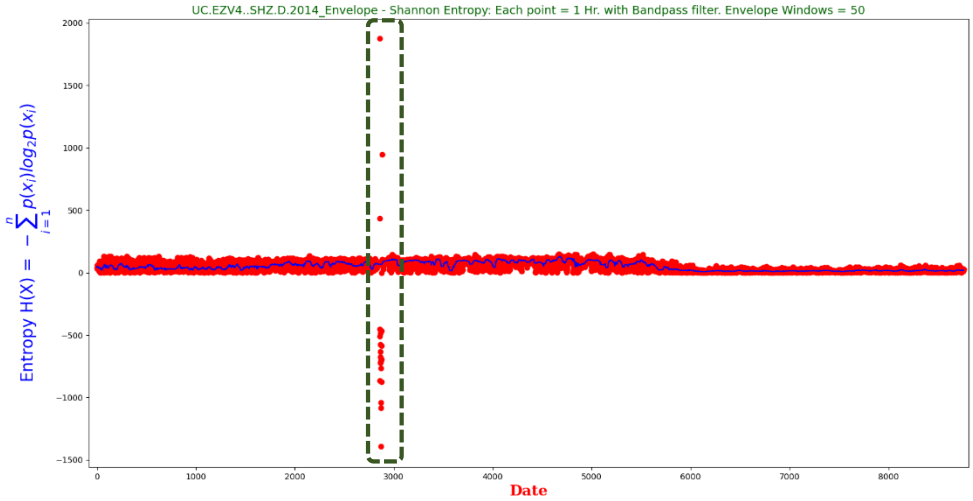

Fig. 53 Graph of Shannon Entropy calculation, showing in the green dotted box, points with values above 500 and negative values.

As shown in the previous figure, several points with values above 500 and also points with negative values can be observed. Zooming in on this image provides a closer look at these values.

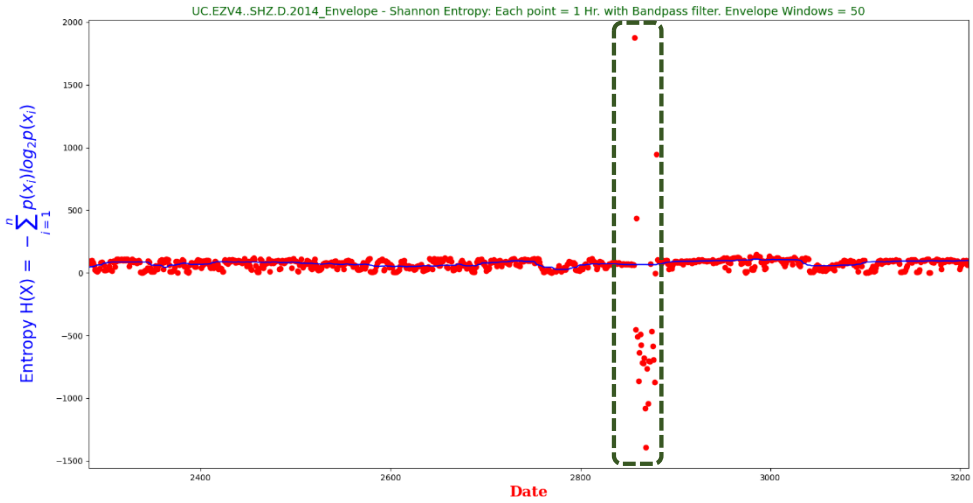

Fig. 54 Zoom in on the Shannon Entropy calculation graph, showing in the green dotted box, points with values above 500, close to 2000, and negative points, close to (-1500).

These points are outside the desired range parameter for entropy. A closer look may reveal the values at which these points are located. It is observed in the following image.

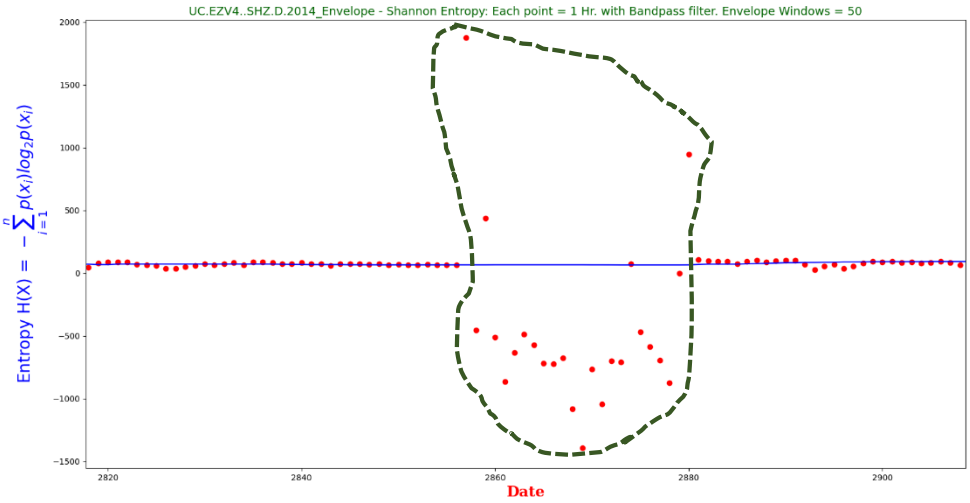

Fig. 55 Graph with a closer zoom to the Shannon Entropy calculation graph. In the area indicated by the green dashed line, points with values above 500, close to 2000, and negative points, close to (-1500), can be observed.

As shown in the previous figure, a closer zoom may indicate or suggest points that introduce a bias and are outside the desired range. Here, it can be inferred that the points are between the values *2850* and *2880*. This is confirmed by analyzing the CSV results file and checking the values between these points. This can be seen in the following image.

2852	119,19,66.55582406043753,0.01848772890567709
2853	119,20,70.08353294457125,0.01946764804015868
2854	119,21,63.967564613123585,0.017768767948089886
2855	119,22,65.72862584928532,0.01825795162480148
2856	119,23,65.14403081737916,0.018095564115938656
2857	120,0,1874.6619477449162,0.5207394299291433
2858	120,1,-453.1711860462806,-0.12588088501285571
2859	120,2,436.02623419831644,0.12111839838842123
2860	120,3,-510.2217419413476,-0.14172826165037433
2861	120,4,-865.1776950144628,-0.24032713750401744
2862	120,5,-634.8714717371098,-0.1763531865936416
2863	120,6,-488.01743623985396,-0.135560398955515
2864	120,7,-573.9585015514801,-0.15943291709763338
2865	120,8,-717.9318725269432,-0.1994255201463731
2866	120,9,-721.302278248241,-0.20036174395784473
2867	120,10,-676.8245641498941,-0.18800682337497057
2868	120,11,-1080.9267640832772,-0.300257434467577
2869	120,12,-1393.575078364087,-0.3871041884344686
2870	120,13,-764.8447614939193,-0.21245687819275538
2871	120,14,-1042.4261250681618,-0.28956281251893384
2872	120,15,-701.5312665896545,-0.19486979627490403
2873	120,16,-708.2074213990579,-0.19672428372196055
2874	120,17,74.39185906898203,0.020664405296939452
2875	120,18,-466.6136646062391,-0.12961490683506643
2876	120,19,-584.9367989026749,-0.16248244413963192
2877	120,20,-693.2978096527612,-0.19258272490354478
2878	120,21,-873.3475226641319,-0.24259653407336998
2879	120,22,-1.1961170936268104,-0.0003322547482296695
2880	120,23,946.0782130488107,0.2627995036246696
2881	121,0,106.61222730756795,0.029614507585435542
2882	121,1,100.00054379802862,0.027777928832785726
2883	121,2,91.31743402070649,0.02536595389464069

High and negative values to eliminate

Fig. 54 Image of the Excel table segment showing the bias interval in points with high and negative values. Intervals between (1874 | -1393).

As observed in the image, the bias of points with high and negative values is between the values 2857 and 2880. These correspond to day 120 in the Julian day (*non-leap year 2014*), i.e., April 30. Probably, on that day, there was a failure or malfunction in the sensor, leading to incorrect readings that result in very high or negative entropy values in the calculation. To address this issue, two possible solutions can be considered.

a) The first option is to leave everything as it is and zoom into the area outside the bias, i.e., the space between values less than 200 and zero. This would result in the following graph.

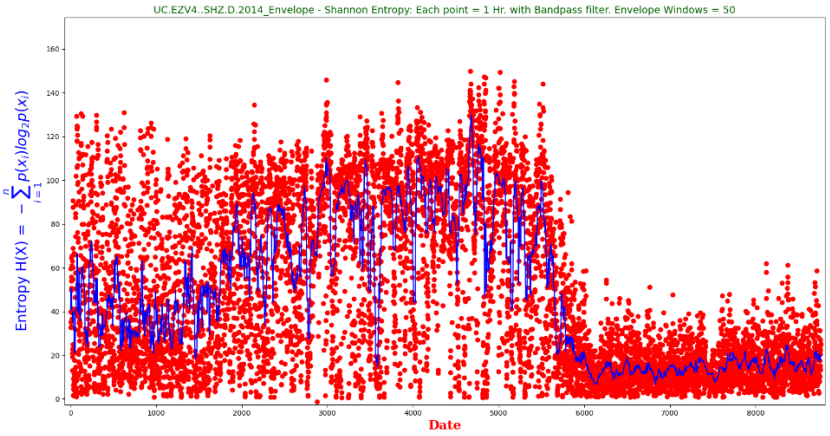

Fig. 57 Image of the Shannon Entropy graph with its envelope, showing the points marked between values less than 200 and zero.

As seen in the above image, the Shannon Entropy graph and its envelope are bounded between average values of 200 to zero. The eruptive period (decay of Shannon entropy) is determined from values 5775 onwards, i.e., from Julian day 241 (non-leap year) according to the Excel table, corresponding to August 29. However, ***both higher and negative values still exist in the graphs***. When zooming into the area delimited by values 2857 and 2880 shown in the Excel table, the following image is presented.

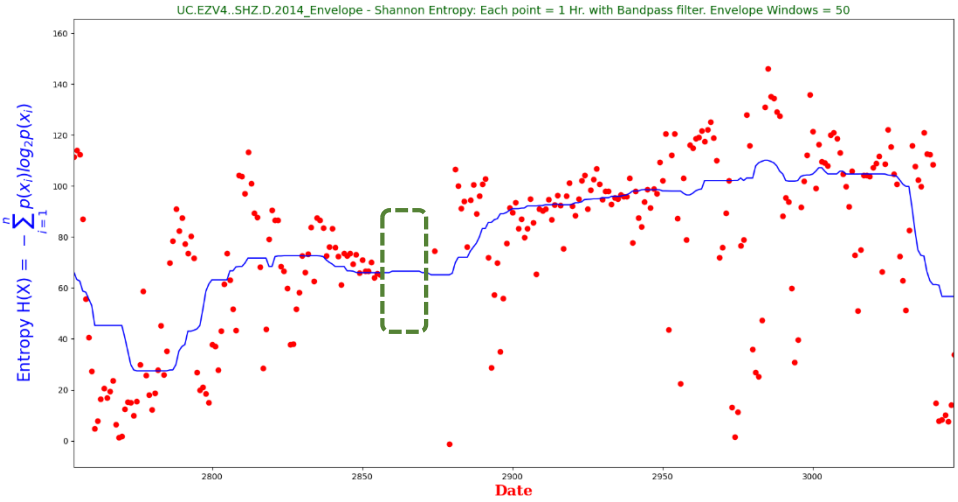

Fig. 58 Graph with a closer zoom to the Shannon Entropy calculation graph with bias. In the area indicated by the green dashed box, there are no associated points; the envelope line follows a straight line because the points have either high or negative values.

b) The second option is to remove from the database (i.e., from the folder where the data is located) the day with bias corresponding to day 120 and repeat the calculation process. This would yield graphs without bias, i.e., with high and negative values replaced by zeros. The resulting graph is as follows.

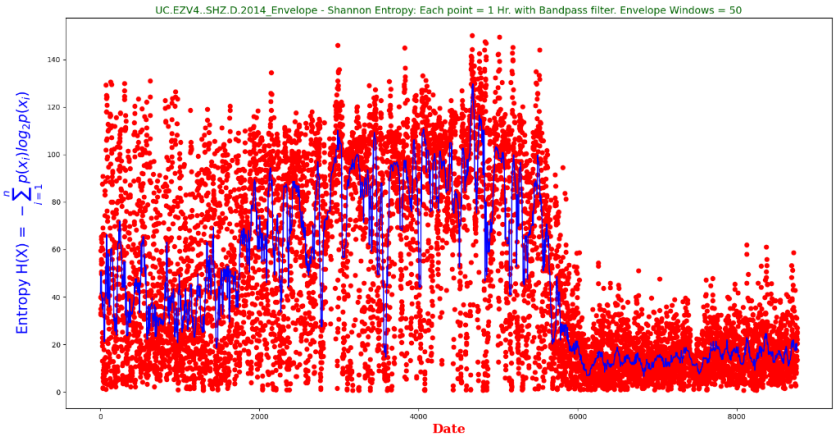

Fig. 59 Image of the Shannon Entropy graph with its envelope after removing day 120, which introduced bias (*2857-2880*) with high and negative values. A year of records in which one day is not noticeable in the final graph.

Upon observing the result graphs in Figure 59 (*entropy with its envelope, as well as the three other graphs*), it can be seen that the result is more uniform after removing the biased day. By excluding that day, non-existent values are replaced by zeros, resulting in a continuous line in the envelope with an area filled with zero values. Only when zooming into the bias area can the result of removing the biased day be observed (*cf. Figure 60*). Since it's a whole year of records, this interval of zeros is irrelevant in the analysis and conclusions of the final result. The user can also choose to cut and paste that fragment afterward in the overall graph.

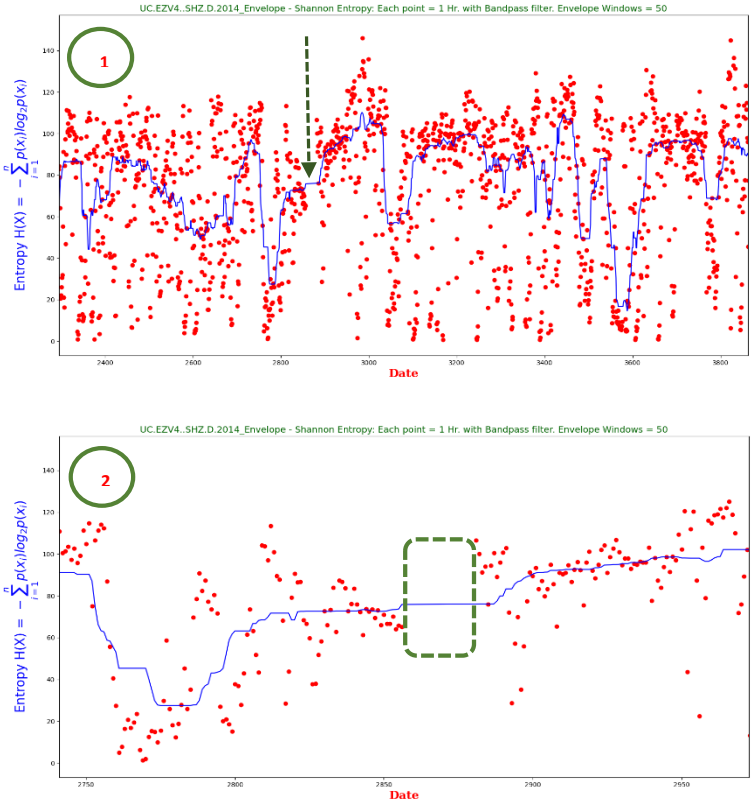

Fig. 60 Image of the Shannon Entropy graph with its envelope after removing day 120, which introduced bias (*2857-2880*) with high and negative values. At the top (**1**), the dashed green line indicates the interval removed from day 120 (*2857-2880*). A closer zoom is observed at the bottom (**2**), in the green dashed box. The bias area (*2857-2880*) shows a horizontal line in the envelope (*as the values are = 0*) and a blank space of points. High and negative values disappear from the graph. Peaks are mostly determined by seismic swarms.

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Comparison of Shannon Entropy and its envelope using analysis windows (10 min, 1 hr, 24 hrs) with the four available filters.

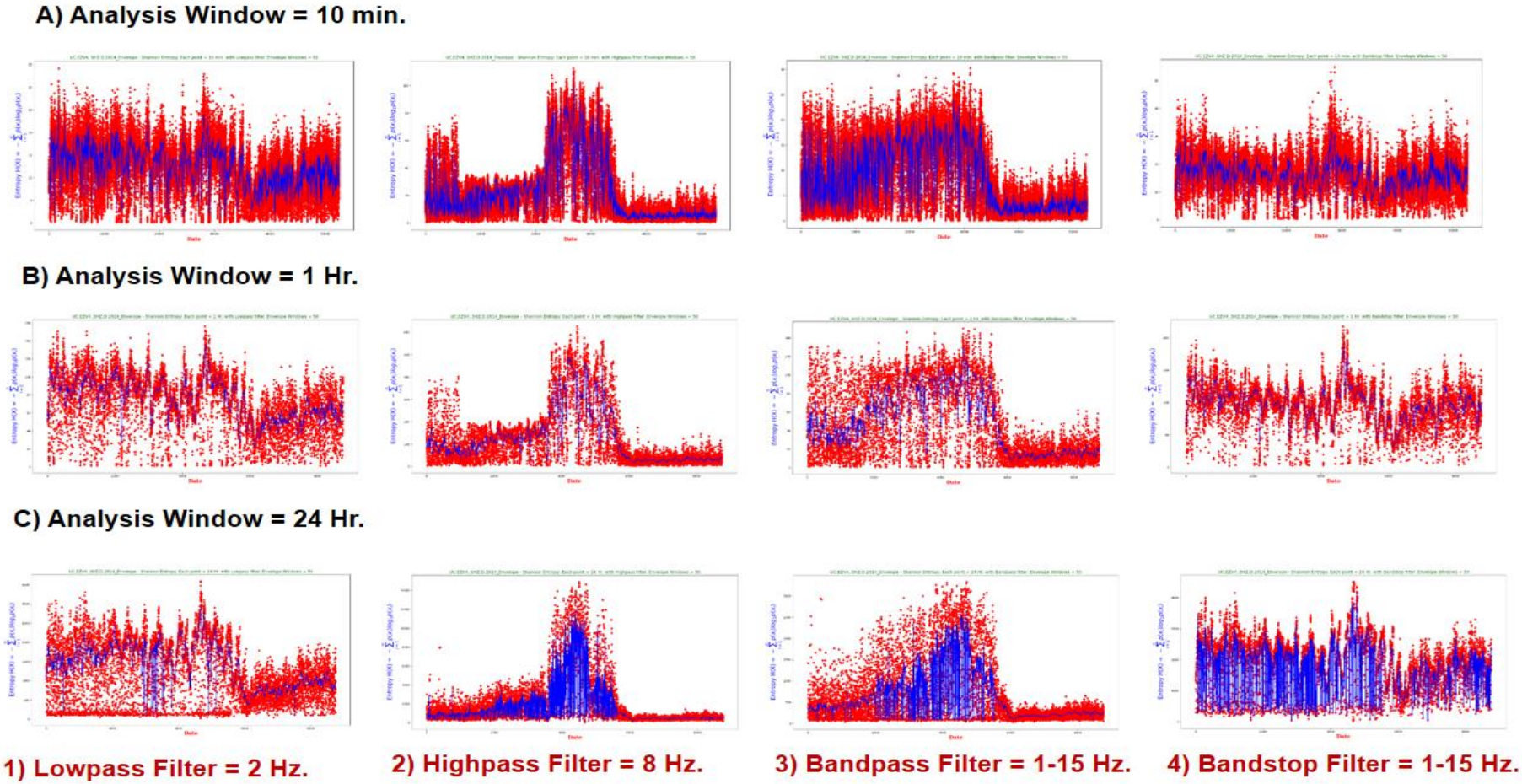

Fig. 61 Comparison of the use of various analysis windows (*10 minutes, one hour, 24 hours*) with the four types of filters. (*Lowpass, Highpass, Bandpass y Bandstop*)

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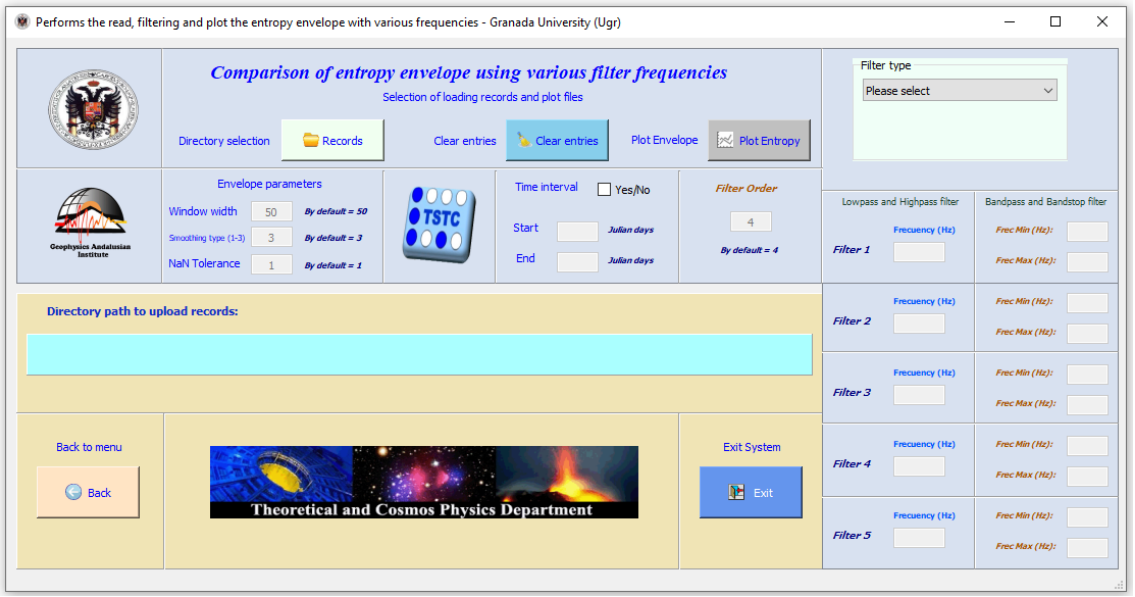
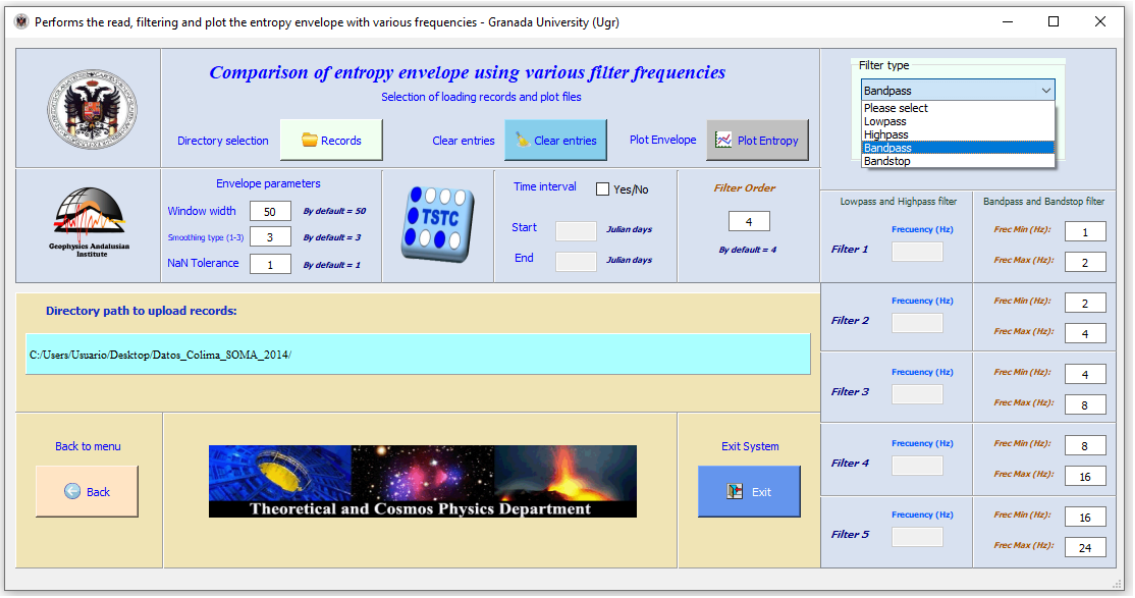
MODULE III

COMPARISON OF SHANNON ENTROPY ENVELOPES USING VARIOUS FILTER FREQUENCIES.





5.- Comparison of Shannon Entropy Envelopes Using Various Filter Frequencies.

The module for comparison, calculation, and graphing of Shannon Entropy envelopes using various filter frequencies (*EnvelopeFilter.py*) allows for reading, filtering, calculation, and graphing of different lines of entropy envelopes. The objective of this second module is to read records contained in a folder for up to one year, including the possibility of selecting time intervals and using filters to calculate entropy with various filter frequencies (*Lowpass, Highpass, Bandpass, and Bandstop*), where each point represents the calculated window value. By default, points are visualized for every hour. The purpose of these graphs is to compare the envelope at different frequencies to observe the decay of entropy and select the most suitable filter and frequency for subsequent analyses.

The interface of this module with its main elements is shown in the following image:

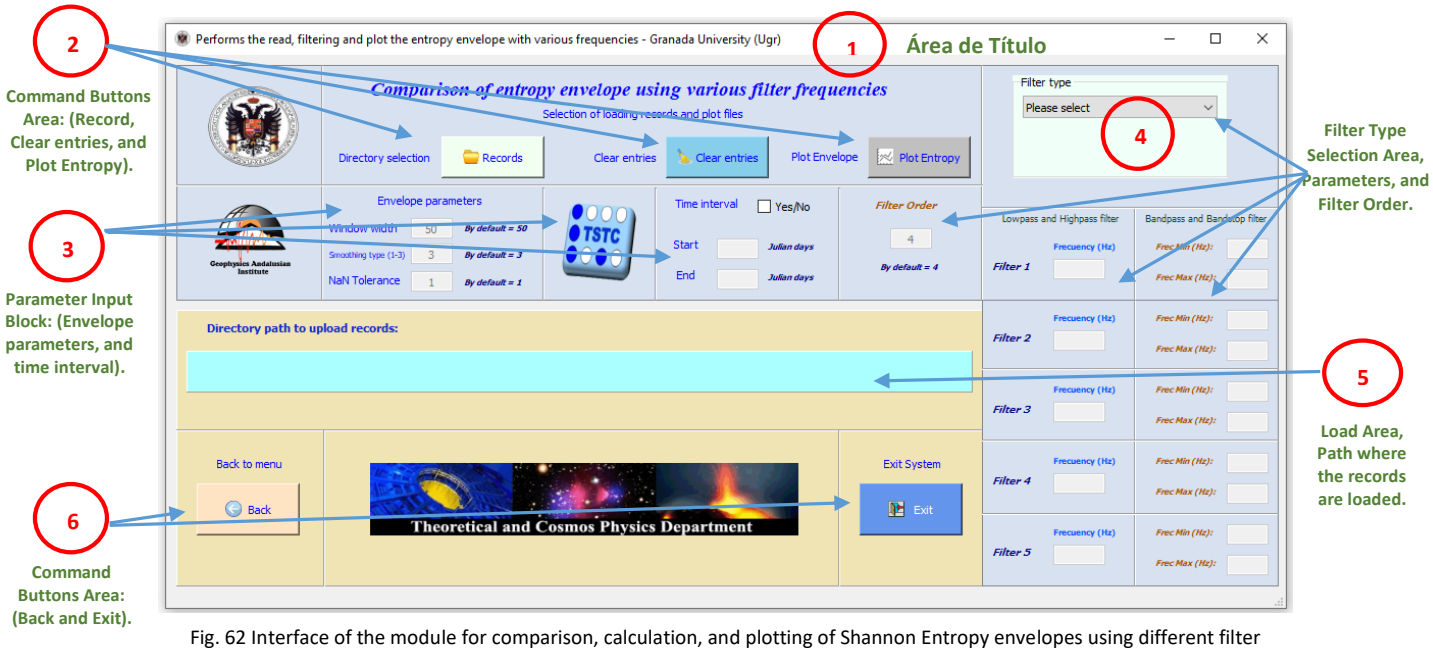


Fig. 62 Interface of the module for comparison, calculation, and plotting of Shannon Entropy envelopes using different filter frequencies and its constituent elements.

As observed in the previous figure, the elements that make up this interface are as follows:

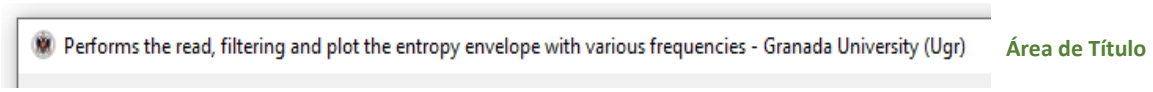
1) Title Area.
2) Command button area: Record, Clear entries, and Plot Entropy.
3) Parameter Input Block: Envelope parameters and time interval.
4) Filter Type Selection Area, Parameters, and Filter Order.
5) Load Area or Path where the records are located.
6) Command button area: Back and Exit.

5.1.- Elements of the Entropy Envelope Comparison Module using various filter frequencies.

The elements that make up the main screen are detailed below.

5.1.1.- Title area. 1

At the top of the module interface screen, the program's name, icon, and university name are displayed as the title (1).



In addition to the title area, number (1), various elements of the interface are observed and are enumerated from (2-6) in red circles. Each of these elements will be described below and includes the following:

5.1.2.- Button Area: (Record, Clear entries, and Plot Entropy). 2

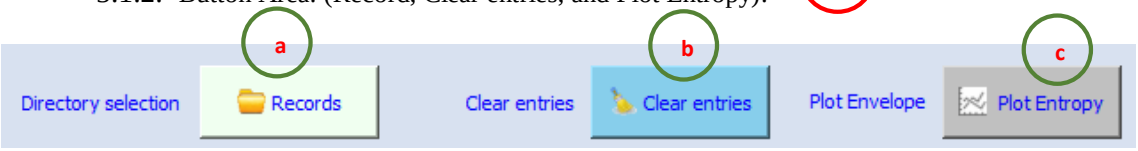
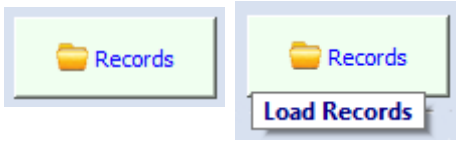


Fig. 63 Button Area: (a) Record, (b) Clear entries, and (c) Plot Entropy.

In the above figure, the functions of the command buttons observed are as follows:

a) Record Button: Loads the physical path "*path*" of the folder where the records to work with are located. When the mouse pointer is placed over it, it displays the text of the action to be performed "*Load Records*".



Clicking the button presents a Windows dialog box that allows the user to select the folder containing the records they want to work with. The dialog box is similar to the one shown below:

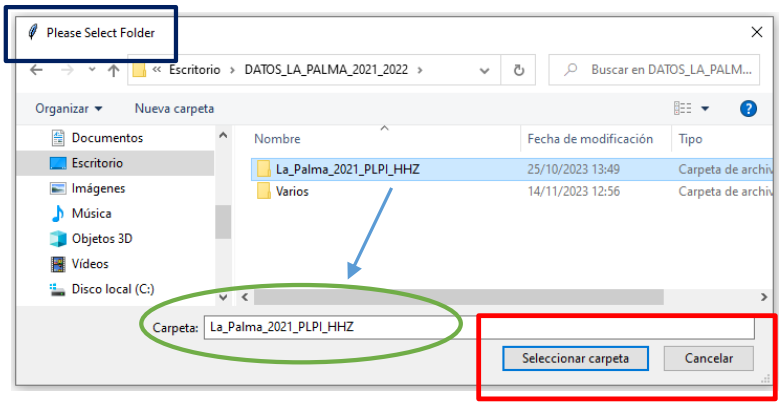


Fig. 64 Dialog box for selecting the folder where the records to work with are located.

As seen in the above image, the user is prompted to select the folder to work with at the top (*blue box*) "*Please Select Folder*". At the bottom (*red box*), there are two action buttons ("Select Folder" and "Cancel") once the folder is selected.

Clicking "*Select Folder*" populates the chosen folder's name, indicated by the arrow in blue, in the "*Folder*" area (*green ellipse*). The path or directory "**Path**" is displayed in the loading section (*Refer to Section 5.1.5*). If the user chooses not to designate a folder, clicking the "*Cancel*" button returns to the main interface for selecting a new folder.

b) *"Clean entries" command button*: Clears or erases input elements, closes existing charts, and resets the analysis screen to its initial state, ready for a new search and calculation of Shannon Entropy with seismic events. (*The text presented when hovering over the button is observed*).

Validation is introduced when executing this button to prevent accidental deletion of user-entered parameters. Clicking this button prompts a dialog box asking the user if they truly want to delete the entries they've made. The dialog box looks like the following:

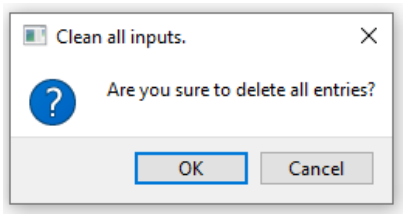


Fig. 65 Dialog box verifying the user's intention to delete entries.

As seen in the figure, if the user indeed wants to delete the entries, they click the "*OK*" button, and all entries are removed. The module's interface then presents the initial values with the checkboxes deactivated. If, on the other hand, the user pressed the clean button by mistake and doesn't want to proceed with this action, they click the "*Cancel*" command button, and the execution returns to the module's interface screen.

c) "*Plot Entropy" command button*: Clicking this button initiates the calculation and obtains the two graphical results for the comparison of Shannon Entropy envelopes (*in lines and dots*).

NOTE: Before clicking, the necessary data entries (*Refer to Section 5.3*) must be introduced, such as the "Path" for the directory of records, the filter type with its input parameters (*analysis window size and envelope*), and whether an interval is to be applied. Clicking the button, if there is any input error, prompts a dialog box indicating it (*Refer to Section 5.2 Validation Messages*). The calculation of Shannon Entropy is then performed, and the two graphical results are presented, comparing the envelopes in lines and dots.

5.1.3.- Parameter input block: Values of the Envelope Window (*Size, Smoothing, and Null Tolerance*), and Time Interval.

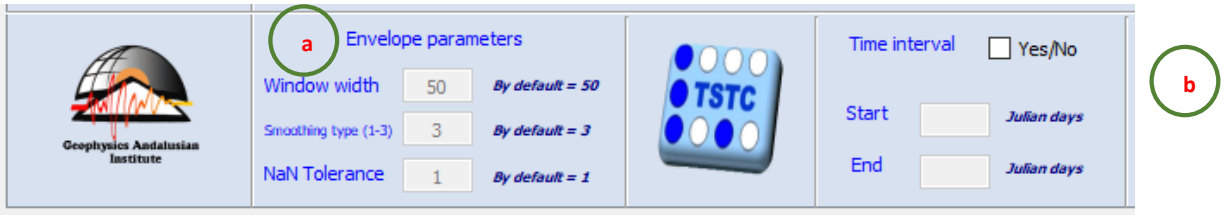
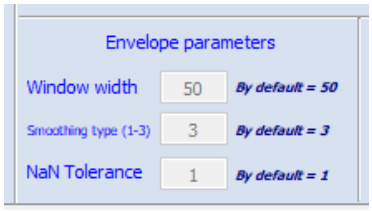


Fig. 66 Parameter input block: (a) Envelope Parameters (Analysis Window Size, Smoothing, and NaN Tolerance), (b) Time Interval

In the previous figure, marked with green circles, two sections comprise this area:

a) Envelope Parameter Selection.



In this box, you enter the envelope parameter values, indicated in three entries:

i) Window size (default is set to 50),
ii) Smoothing type (default is set to 3),
iii) NaN null value tolerance (default is set to 1).

NOTE: The user can leave the default number when selecting the data folder to work with, even if the number of records is lower. This merely indicates the maximum number of data points to be considered. If the user wishes to work with a smaller number, for example, a month, the easiest and most viable option is to use the time interval (**c**) and indicate it there, leaving this value as the default to represent the maximum size for analysis.

b) Selection of the time interval.

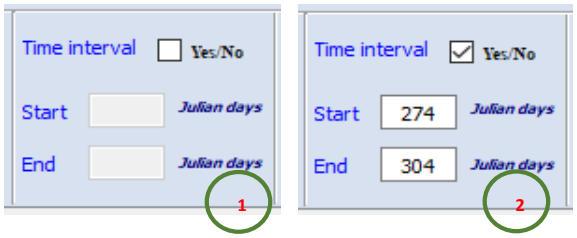


Fig. 67 User's indication whether a time interval will be used to analyze the data (**1**) Initial position, empty value in the "*Yes/No*" box, indicating "**NO**". (**2**) Check the "*Yes/No*" box, indicating "**YES**", which activates the text boxes "Start" and "End" when selecting the filter, to enter the dates in Julian days (274 to 304), corresponding to analyzing the month of October in a non-leap year.

In the previous box, it is observed that part (**1**) has the initial default values. That is, it is not selected to use the time interval, and the text boxes indicating the date entries in Julian days are deactivated. In part (**2**), the "*Yes/No*" box has been selected or checked, indicating the desire to use the time interval. To do this, the user needs to select the filter type, which activates the start (*Start*) and end (*End*) date text boxes, expressed in Julian days. In the example shown in the figure, the start and end dates have been entered as values (*274-304*) respectively, indicating the analysis of records for the month of October in a non-leap year (*2015, 2017, 2019, 2021, 2023, etc.*). Data entry in these boxes is validated to accept only integers, positioned in the center of the box.

5.1.4.- Filter Type Selection Area, Parameter Entry, and Filter Order.

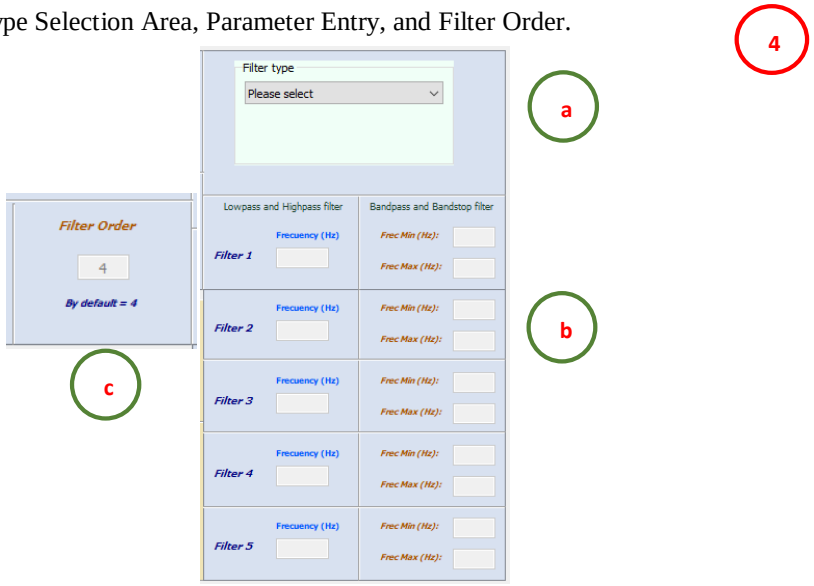
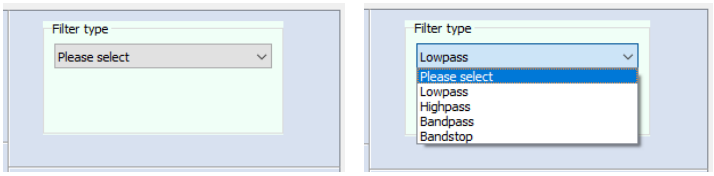


Fig. 68 Filter Selection Area: (**a**) Filter type selection, (**b**) Filter type parameters, (**c**) Filter order.

The comparison of entropy envelopes is performed by selecting five different parameter sets. That is, five frequency intervals of a specific filter type are chosen. Hence, there are five parameter entry boxes in the image. In the figure above, marked with green circles, three sections comprise this area:

a) Filter Type Selection Area.



In the above image, the left part initially instructs the user to perform or select the type of filter they want to use. By clicking on this dropdown (*ComboBox*), the available filter options are presented, which are: (*Lowpass*[10]), (*Highpass*[11]), (*Bandpass*[12]) and (*Bandstop*[13])

[10] **Lowpass Filter:** The lowpass filter blocks high-frequency signals and allows low-frequency signals to pass through (*frequencies lower than the cutoff frequency*).

[11] **Highpass Filter:** The highpass filter blocks low-frequency signals and allows high-frequency signals to pass through (frequencies higher than the cutoff frequency).

[12] **Bandpass Filter:** The bandpass filter allows spectral content only in the vicinity of the central frequency. This window is created through a minimum frequency value and a maximum frequency value. It eliminates noise associated with low and high frequencies generated and/or residual.

[13] **Bandstop Filter:** The bandstop filter does not allow the passage of signals whose frequencies are between the upper and lower cutoff frequencies. In other words, it eliminates frequencies or stops a particular frequency band.

NOTE: By default, the command button for the calculation and presentation of Shannon entropy results (*Plot Entropy*) is disabled. This button is activated once the user has selected the filter type.

b) Area for selecting and entering filter parameters.

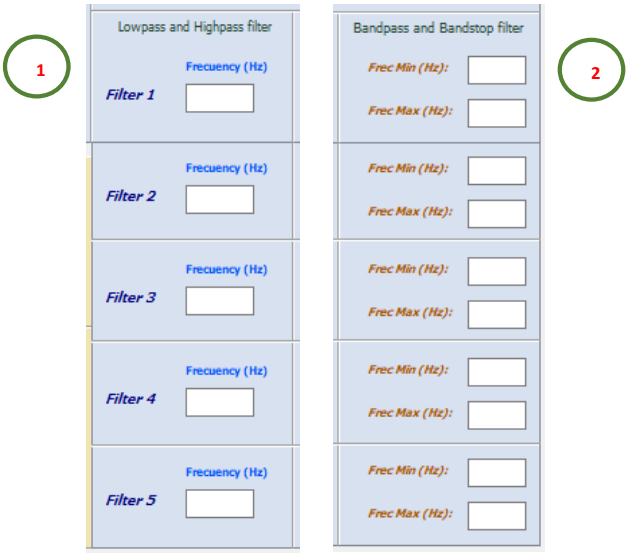


Fig. 69 Filter Parameter Selection Area: (**1**) Frequency parameter (Hz) [Lowpass and Highpass filters], (**2**) Minimum and maximum frequency parameters (Hz) [Bandpass and Bandstop filters].

1) Frequency Parameter (Hz): These five boxes are activated when selecting filter types; *Lowpass* and *Highpass*. In this selection, the minimum and maximum frequency boxes remain deactivated. Entries in this box are validated to allow decimal numbers.

2) Minimum and Maximum Frequency Parameters (Hz): These five sets of two text boxes are activated when selecting filter types; *Bandpass* and *Bandstop*. In this selection, the Frequency (Hz) input boxes are deactivated. Entries in these five sets of boxes are validated to allow decimal numbers.

NOTE: In the image above, all data entry boxes that are initially observed are deactivated by default. They are also validated to only allow numerical inputs and not alphabetical characters or letters. The values to be entered will be centered in the text boxes.

c) Filter Order Parameter: By default, this parameter is set to a value of four (4) initially. This input box is activated when selecting any of the four available filter types. It allows the user to enter a different filter order value (*2, 6, 8, etc.*). Entry in this box is validated to accept only integers.

5.1.5.- Loading area or path, of the directory and records to be used. 5

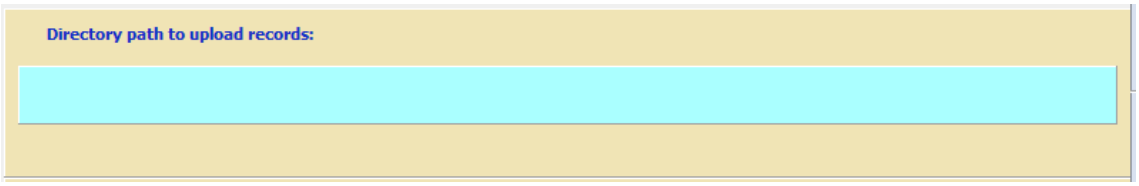


Fig. 70 Loading area or path, of the directory and records to be used.

In this previous image, the area is shown where the directory or folder path will be displayed, in which the actions of the command button: "*Records*" will be carried out, as described in section 5.1.2.

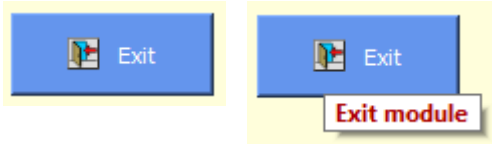
NOTE: It is important that this area is already defined before proceeding to click or execute the "*Plot Entropy*" command button (*See section 5.1.2*), which will perform the calculation, comparison, and printing of results of the five Shannon Entropy envelopes, according to the data indicated in the working directory or folder and the parameters of the selected filters. Otherwise, validation dialog boxes for data entry will be presented (*See section 5.2*).

5.1.6.- Command button area: (*Back and Exit*).

Fig. 71 Command Button Area: (a) Back and (b) Exit.

a) "***Back***" command button: Allows you to return to the initial presentation screen of the system (Main Menu). When placing the mouse pointer, it displays a message indicating its function.

b) "***Exit***" command button: Allows the complete exit from the module and system (*After presenting the screen that asks if you want to leave the module and system*). When placing the mouse pointer, it displays a message indicating its function.



As in the start screen, if the "Exit" button is pressed or clicked, a window appears asking the user if they are sure they want to leave the module and system. This window is the following.

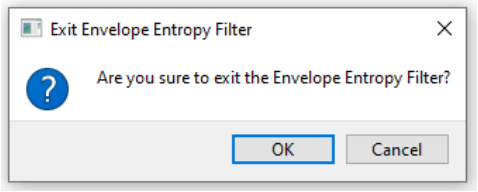


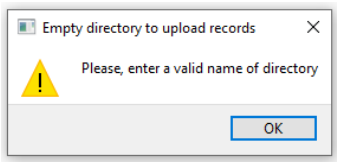
Fig. 72 Text box indicating whether you want to exit the module and system.

Clicking "OK" closes the screen and completes the module and system exit. Clicking "Cancel" continues to the main screen of the Shannon Entropy envelope calculation and comparison module.

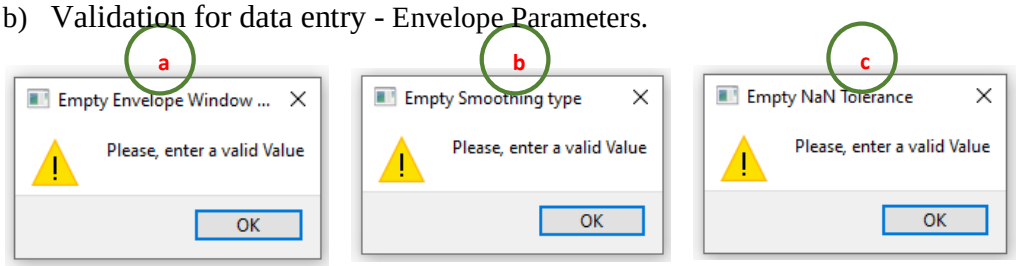
5.2.- Error Validation for Directory or Input Entries.

If you attempt to calculate and graph the comparison of Shannon Entropy envelopes by clicking the "Plot Entropy" button without entering data in any of the input parameter boxes or text fields, a validation prompt will appear, indicating that this action must be performed. These validation prompts allow the program execution to proceed without severe system interruption due to missing data. The validations for empty or incorrect entries are as follows:

a) Validation for data entry - Records directory empty.

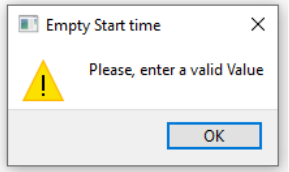


b) Validation for data entry - Envelope Parameters.

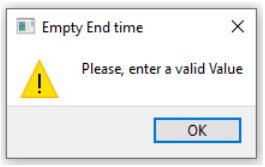


(a) Empty Envelope Size value. (b) Empty Smoothing value. (c) Empty NaN Tolerance value.

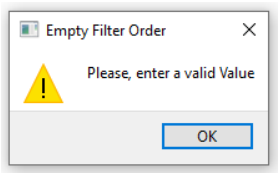
c) Validation for data entry - Start Time Interval empty.



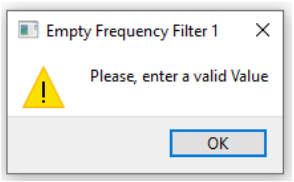
d) Validation for data entry - End Time Interval empty.



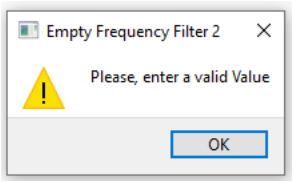
e) Validation for data entry - Filter order empty.



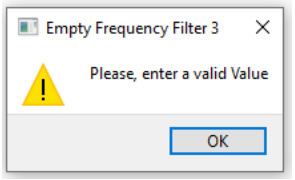
f) Error Validation for Data Entry – Empty Frequency Value (*Lowpass or Highpass*) Filter 1.



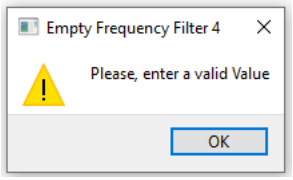
g) Error Validation for Data Entry – Empty Frequency Value (*Lowpass or Highpass*) Filter 2.



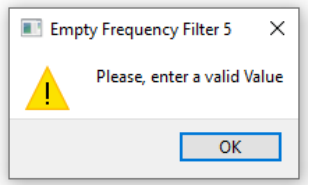
h) Error Validation for Data Entry – Empty Frequency Value (*Lowpass or Highpass*) Filter 3.



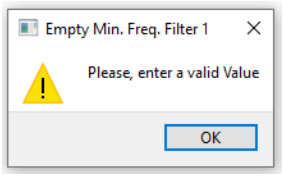
i) Error Validation for Data Entry – Empty Frequency Value (*Lowpass or Highpass*) Filter 4.



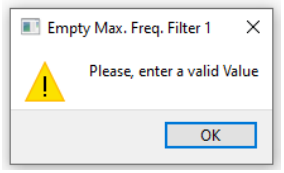
j) Error Validation for Data Entry – Empty Frequency Value (*Lowpass or Highpass*) Filter 5.



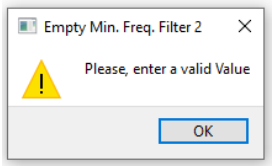
k) Error Validation for Data Entry – Empty Minimum Frequency Value (Bandpass or Bandstop) Filter 1.



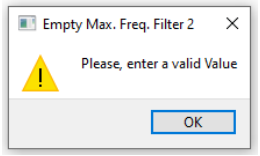
l) Error Validation for Data Entry – Empty Maximum Frequency Value (*Bandpass or Bandstop*) Filter 1.



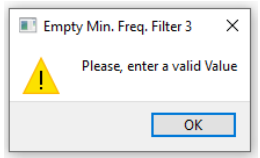
m) Error Validation for Data Entry – Empty Minimum Frequency Value (*Bandpass or Bandstop*) Filter 2.



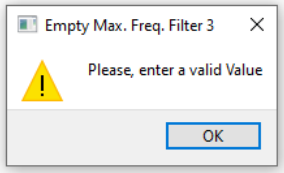
n) Error Validation for Data Entry – Empty Maximum Frequency Value (*Bandpass or Bandstop*) Filter 2.



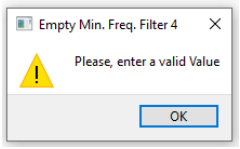
o) Error Validation for Data Entry – Empty Minimum Frequency Value (*Bandpass or Bandstop*) Filter 3.



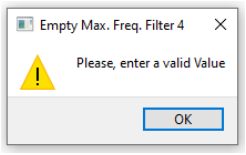
p) Error Validation for Data Entry – Empty Maximum Frequency Value (*Bandpass or Bandstop*) Filter 3.



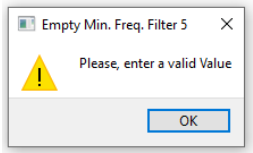
q) Error Validation for Data Entry – Empty Minimum Frequency Value (*Bandpass or Bandstop*) Filter 4.



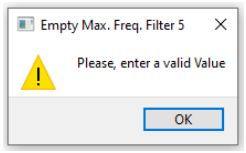
r) Error Validation for Data Entry – Empty Maximum Frequency Value (*Bandpass or Bandstop*) Filter 4.



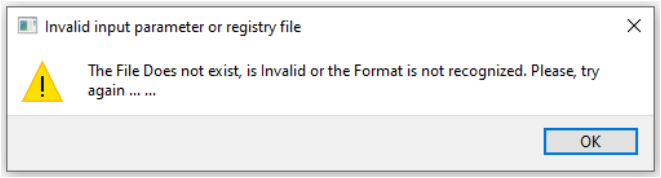
s) Error Validation for Data Entry – Empty Minimum Frequency Value (*Bandpass or Bandstop*) Filter 5.



t) Error Validation for Data Entry – Empty Maximum Frequency Value (*Bandpass or Bandstop*) Filter 5.



u) Validation in case of encountering a different input error than the ones mentioned earlier, such as a non-existent or invalid file.



The message in the above figure indicates an input error (*different from the previous ones*) because the format is not recognized, it is invalid, or the record does not exist. Additionally, the parameters or inputs may be outside the allowed range according to the signal to be analyzed. By clicking the "*OK*" button, you return to the system to choose a valid file or correct the erroneous inputs. This way, the program's execution continues without issues.

5.3.- Execution process and results of the Shannon Entropy Envelopes Comparison Module using various filter frequencies.

The process for loading, filtering, and graphing the comparison of envelopes based on filter values is straightforward, consisting of the following steps (*It is recommended to follow these steps*):

a) Select the directory where the records are located by clicking the "*Records*" command button. By default, the initial path is set to the root directory "**C**" of the PC, whether on the Windows or Linux system. Once selected, click the "*Open*" command button, and the file path is displayed in the area: (*Directory path to upload records - See 5.1.5*).
b) Select the filter type (*Lowpass, Highpass, Bandpass, or Bandstop*). This will activate the parameter entry boxes based on the indicated selection.
c) Select and enter the Envelope parameters or leave the default values = (50,3,1).
d) (OPTIONAL) Select or check the box (*if required*) to analyze a specific time interval. If affirmative, indicate in the "*Start*" box the start time in Julian days and in the "*End*" box the end time in Julian days.
e) Enter the filter parameter values according to the selected type. For lowpass and highpass filters, enter a valid "*frequency*" value for the five proposed values (*Filter 1 to Filter 5*). For bandpass and bandstop filters, enter valid "*minimum frequency*" and "*maximum frequency*" values for the five proposed values (*Filter 1 to Filter 5*).
f) Enter (*if required*) the filter order or leave the default value = 4.
g) Finally, click the "Plot Entropy" button to calculate Shannon Entropy, and present the two graphs comparing the envelopes (*in lines and dots*).

Once the above is done, click the "*Plot record*" command button. The output of this process will consist of two graphs (*1.- Comparison of Shannon Entropy Envelopes using line plots for the five filter parameters, 2.- Comparison of Shannon Entropy Envelopes using dot plots for the five filter parameters*). When the graphs are displayed, you can zoom in (*using the "Magnifying Glass " tool number 5 - See Section 6*) at any part of them to observe the entropy's progression over time in much greater detail.

5.3.1.- Example of the Shannon Entropy Envelopes calculation and comparison procedure using various filter frequencies.

As an example, the following process is presented in the interface with the output elements for an analysis of the comparison of Shannon Entropy envelopes using various filter frequencies.

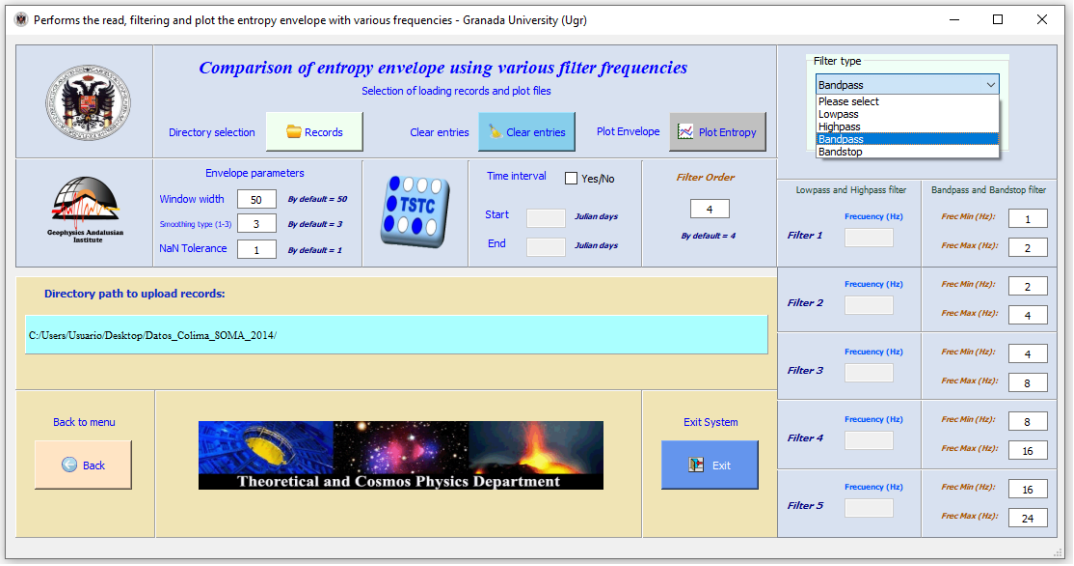


Fig. 73 Interface of the module with the module's input for the calculation and comparison of Shannon Entropy envelopes using various filter frequencies.

In the above figure, the values obtained when loading records for a one-year duration are observed (*The time interval field is not used*). The input parameters used are:

a) Select and enter the Envelope parameters (*Envelope size, Smoothing and NaN Tolerance*) or leave the default values = (*50,3,1*).
b) Filter Type: In this case = *Bandpass*.
c) Enter the 5 sets of input parameters for the Bandpass Filter.
    a. Filter 1: Minimum Frequency = 1, Maximum Frequency = 2.
    b. Filter 2: Minimum Frequency = 2, Maximum Frequency = 4.
    c. Filter 3: Minimum Frequency = 4, Maximum Frequency = 8.
    d. Filter 4: Minimum Frequency = 8, Maximum Frequency = 16.
    e. Filter 5: Minimum Frequency = 16, Maximum Frequency = 24.
d) Filter order. (*If required*), otherwise leave the default value = 4.

As observed, the user only had to specify the folder where the data is located, the filter type, and its parameters. The remaining input values are presented by default. Subsequently, click the "*Plot Entropy*" command button, proceed to the calculation, and present the results. The two result graphs (*lines and dots with their zoom-ins*) obtained from this procedure are as follows:

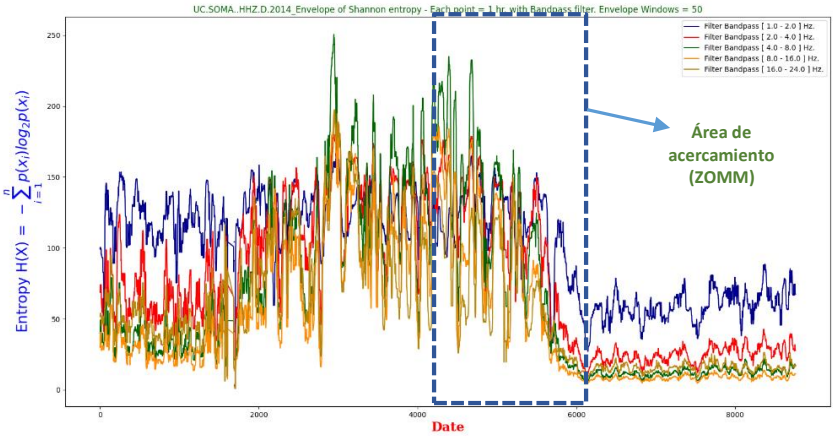


Fig. 74 Graph (lines) comparing envelopes using the 5 sets of bandpass filter values.

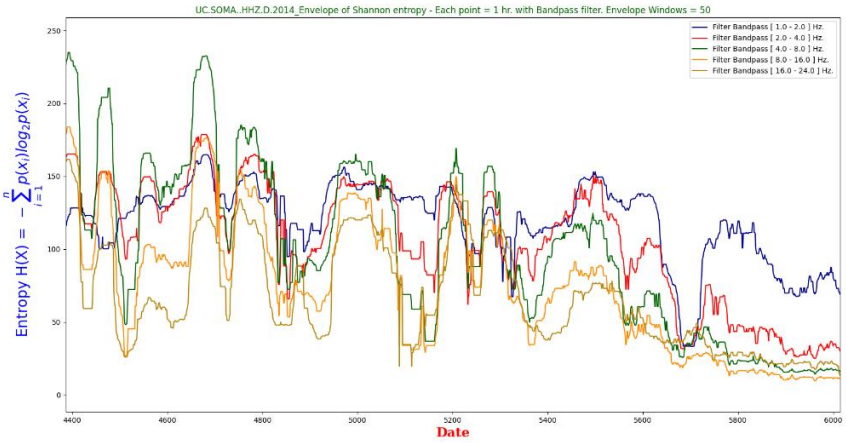


Fig. 75 Zoomed-in view (*interval 4400-6000 in the dotted blue box, figure 70*), Graph (*lines*) comparing envelopes using the 5 sets of bandpass filter values.

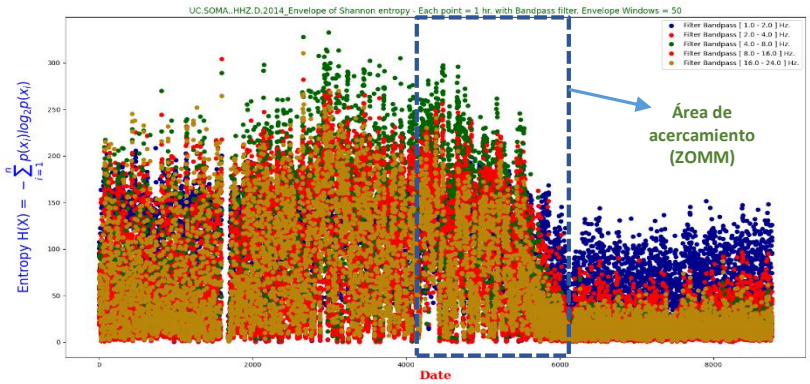


Fig. 76 Graph (dots) comparing envelopes using the 5 sets of bandpass filter values.

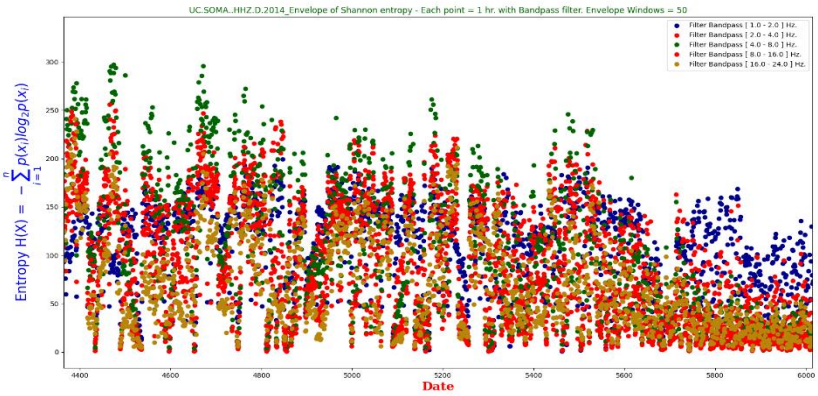


Fig. 77 Zoomed-in view (*interval 4400-6000 in the dotted blue box, figure 72*), Graph (*dots*) comparing envelopes using the 5 sets of bandpass filter values.

5.3.2.- Example Procedure for Calculating and Comparing Shannon Entropy Envelopes Using Various Filter Frequencies, Taking a Time Interval as Parameters.

The previous graphs correspond to records spanning one year (**2014**). Each graph provides a close-up of a specific area (*dotted blue box*). The following images illustrate taking a time interval as a parameter.

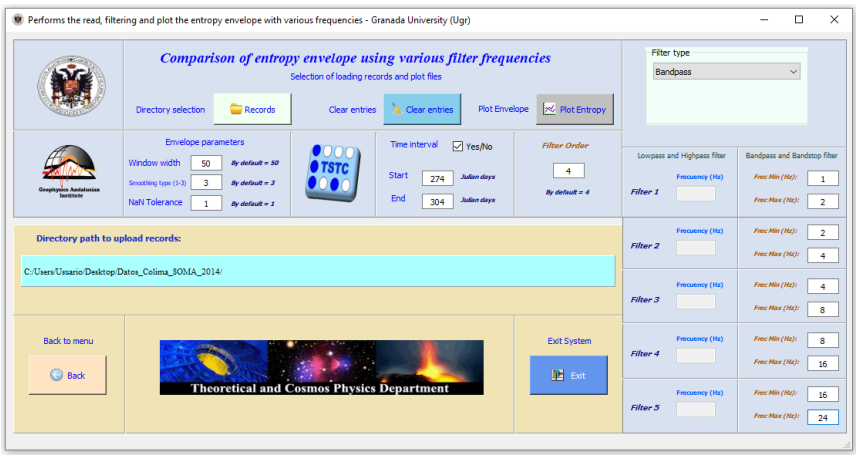


Fig. 78 Interface of the module's input for the calculation and comparison of Shannon entropy envelopes using various filter frequencies and a time interval from Julian day 274 to 304, corresponding to the month of October (non-leap year).

In the example shown in the module interface in the previous figure, the start and end dates are set to values **274-304**, meaning that the analysis will focus on records from the month of **October** in a non-leap year (*2014, 2015, 2017, 2019, 2021, 2023, etc.*). Data entry in these boxes is validated to accept only integers, positioned in the center of the box.

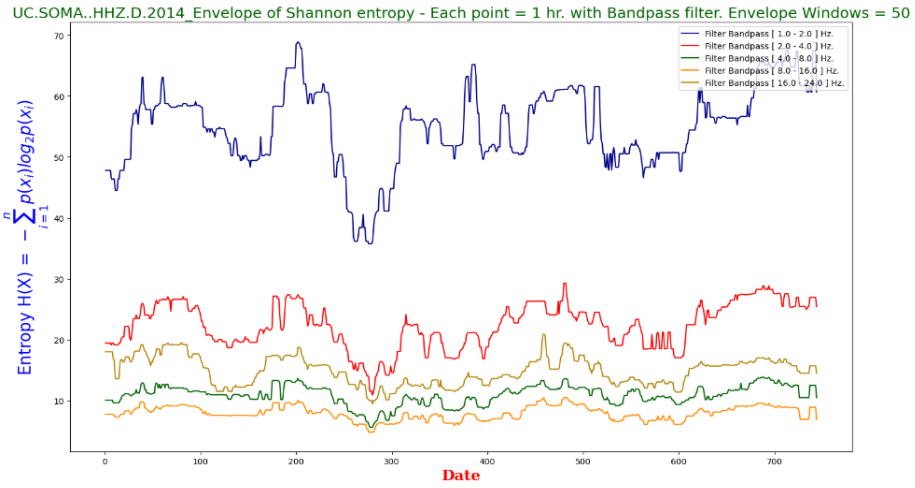


Fig. 79 Graph (*lines*) comparing envelopes using the 5 sets of bandpass filter values, using a time interval (*Julian days 274-304*), equivalent to October 2014.

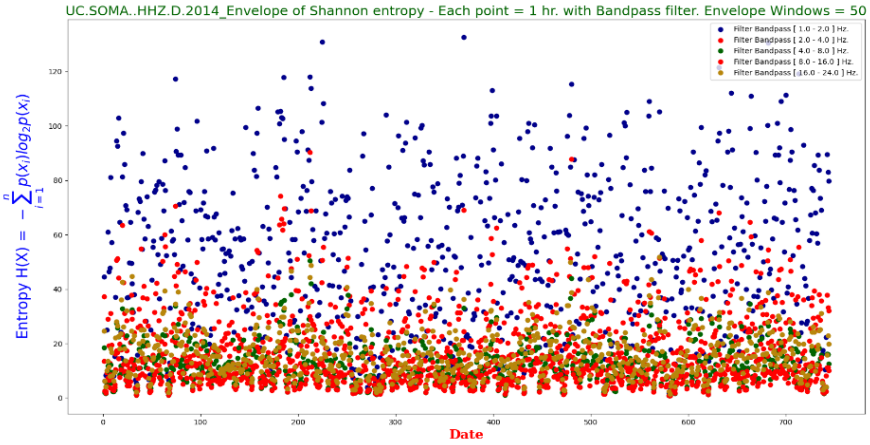


Fig. 80 Graph (*dots*) comparing envelopes using the 5 sets of bandpass filter values, using a time interval (*Julian days 274-304*), equivalent to October 2014.

As observed in both the images comparing envelopes for the entire year (*Figs. 74-77*) and those for the time interval (*Figs. 79-80*) with a bandpass filter, the two frequency ranges that approach zero for Shannon Entropy analysis would be the filters at frequencies (*4-8 Hz and 8-16 Hz*). However, this cannot be a general constant because variations may occur depending on the volcano and the type of eruption it exhibits.

For example, in the following section, a comparison is presented between the analysis of envelopes from an explosive eruption and an effusive eruption using two different volcanoes located in diverse geographical areas.

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5.3.3.- Example Procedure for Calculating and Comparing Shannon Entropy Envelopes Using Various Filter Frequencies, Taking Two Types of Volcanoes and Eruptions as Reference.

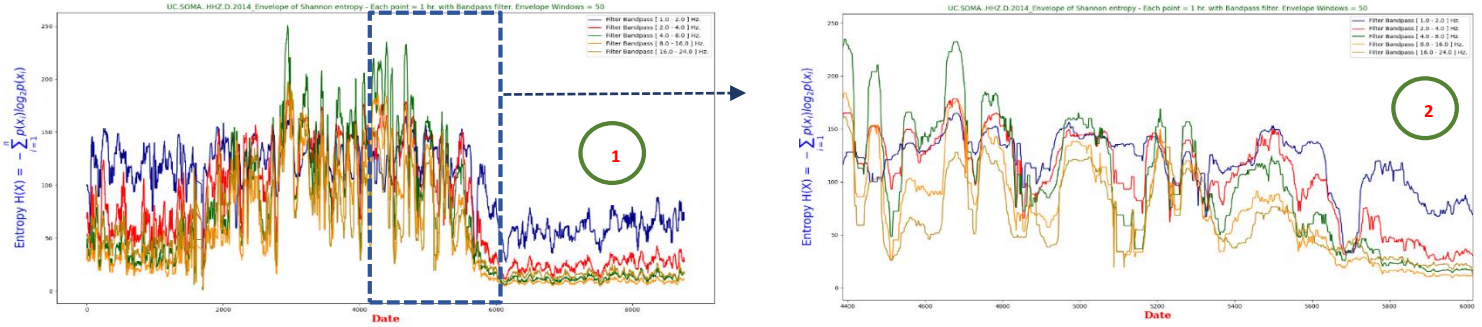


Fig. 81 Volcano and explosive eruption type. (**1**) Graph (lines) comparing envelopes using the 5 sets of bandpass filter values. (**2**) Zoomed-in view (*interval 4400-6000 in the dotted blue box*), Graph (lines) comparing envelopes using the 5 sets of bandpass filter values.

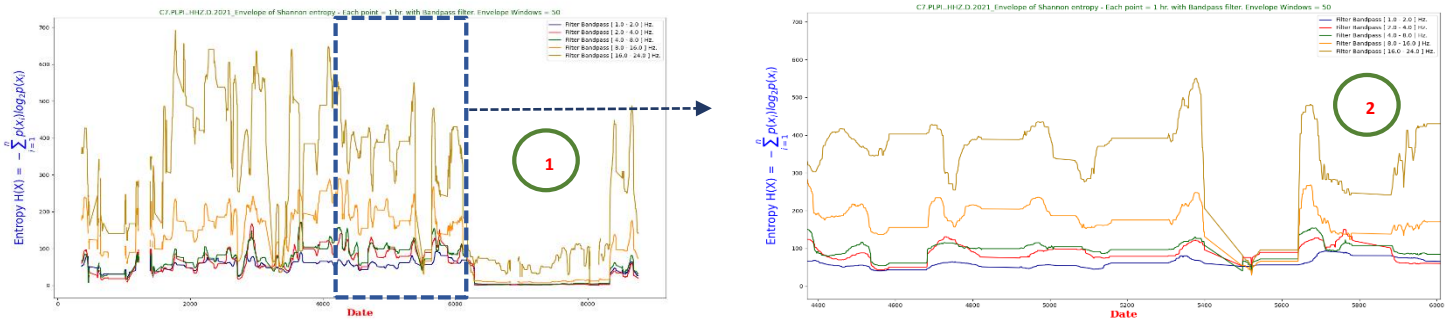


Fig. 82 Volcano and effusive eruption type. (**1**) Graph (lines) comparing envelopes using the 5 sets of bandpass filter values. (**2**) Zoomed-in view (*interval 4400-6000 in the dotted blue box*), Graph (lines) comparing envelopes using the 5 sets of bandpass filter values.

As observed in the previous figures, the upper graph (Fig. 81) for the explosive eruption indicates that the envelopes for one year show a better analysis of Shannon Entropy (*trending towards zero*) in the frequency filters (*4-8 Hz and 8-16 Hz*). However, the lower graph (Fig. 82) for the effusive eruption indicates that the envelopes for one year show a better analysis of Shannon Entropy (trending towards zero) in the frequency filters (*1-2 Hz and 2-4 Hz*). Similarly, the filter from 16 to 24 Hz performs better in the explosive eruption than in the effusive one.

It can be concluded from the above results that for each type of eruption and volcano, the user should analyze and decide which type of filter and frequencies are most suitable for that particular case. Proceeding in this way, with the Shannon Entropy calculation and its envelope, using the most appropriate parameters. To reinforce this, we will observe the graphs when taking a time interval. Thus, as in the previous figures, the values (*274-304*) will be analyzed, meaning that records from the month of October in a non-leap year (*2014, 2015, 2017, 2019, 2021, 2023, etc.*) will be analyzed. The images are as follows.

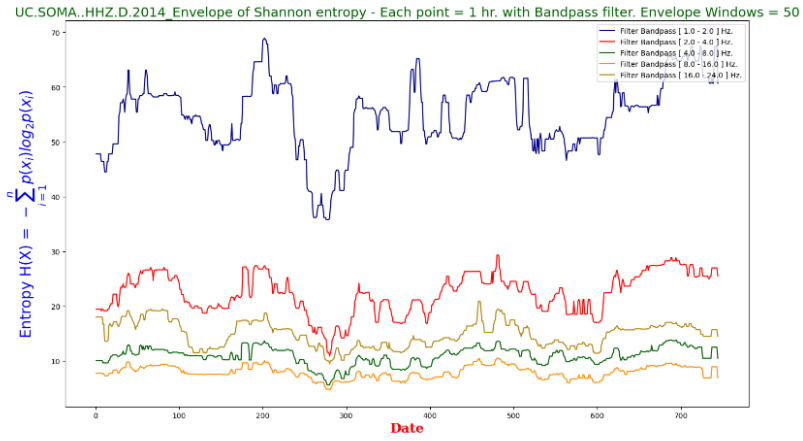


Fig. 83 Volcano and explosive eruption type. Graph (lines) comparing envelopes using the 5 sets of bandpass filter values, using a time interval (*Julian days 274-304*), equivalent to October 2014.

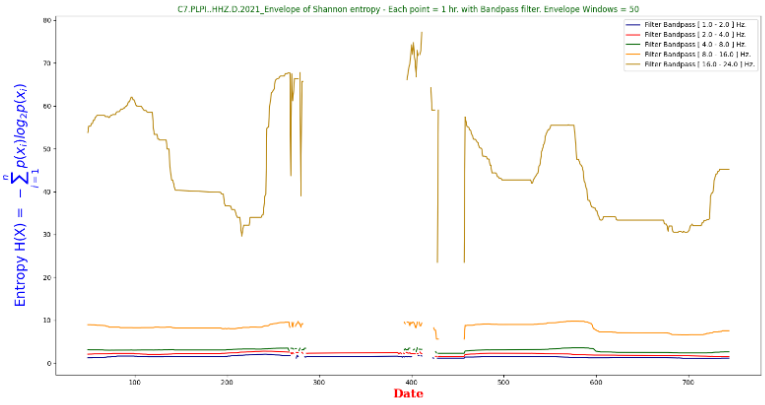
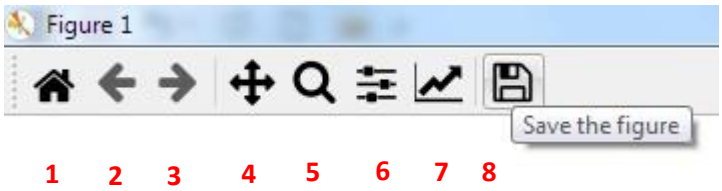


Fig. 84 Volcano and effusive eruption type. Graph (lines) comparing envelopes using the 5 sets of bandpass filter values, using a time interval (*Julian days 274-304*), equivalent to October 2021.

As in Figures 81 and 82, it can be observed that the most suitable filters [*in this case, bandpass (Bandpass)*] for calculating Shannon Entropy to establish a trend towards zero in both eruptions are: (a) For the explosive eruption, it is (*4-8 Hz and 8-16 Hz*), and for the effusive eruption, it is (*1-2 Hz and 2-4 Hz*).

6.- Toolbar of Graphs (Matplotlib Library)

In the construction of graphs, the *Matplotlib* library's graph screen has a set of very useful tools that allow you to visualize, edit, and save graphs in various formats. At the top of the Matplotlib graph screen that appears when a graph is created, there is a toolbar similar to the following:



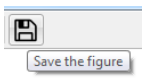
From left to right, the icons representing the actions to be performed are:

1. Reset original view: Restores all graphs to the initial state.
2. Back to previous view: Preview of the selected graph.
3. Forward to next view: Forward view of the next image.
4. Left button pans, Right button zooms, x/y fixes axis, CTRL fixes aspect. Moves the graph and axes left or right, zooms in or out, fixes the x/y axis, and fixes the aspect with CTRL.
5. Zoom to rectangle: Through a rectangle, zooms in on the selected graph.
6. Configure subplots: Configuration of subplots (Borders and spacings).
7. Edit axis, curve and image parameters: Editing the parameters of the graph. Select the axes or graph and edit elements such as title, coordinates (X, Y), and curve parameters (lines, markers) in styles, colors, and size.
8. Save the figure: Saves the graph in several formats.

This document does not delve into each of them; it only highlights the use of those that are generally more commonly used, such as (1, 2, 5, 7, and 8).

In the above graphs, the use of the zoom tool (5) has been observed. Tools 2 and 3 allow zooming in or out individually for each graph. Option 1 allows restoring all elements or subplots of the graph to their initial values (*each individual graph or part of the window*). As for option 8, it allows saving the graph in various formats. The rest are straightforward, and it is up to the user to explore each of them. Now, the processes for "***editing***" and "***saving*** or ***storing***" the graphs (*Numbers 7 and 8*) are detailed below.

6.1.- Saving Graphs.

The process of saving graphs is very simple. Click on the icon of tool number 8 (Save the figure). 

This opens an explorer window, similar to those in Windows (depending on the language or system used), where you can select the folder or directory where the graph will be saved.

Additionally, provide a name and select the desired format type. This can be done at the bottom of the explorer window (red circle in the image), where various format types available for saving are selected. The screen resembles the following.

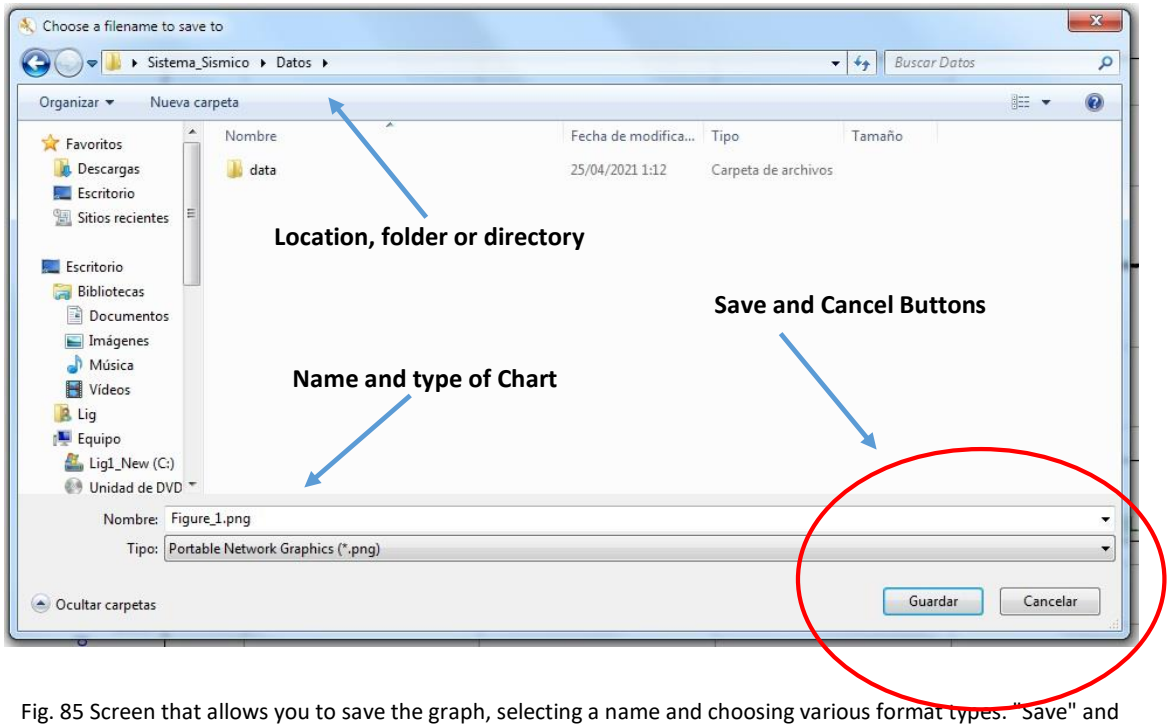


Fig. 85 Screen that allows you to save the graph, selecting a name and choosing various format types. "Save" and "Cancel" buttons are provided to complete or cancel the process.

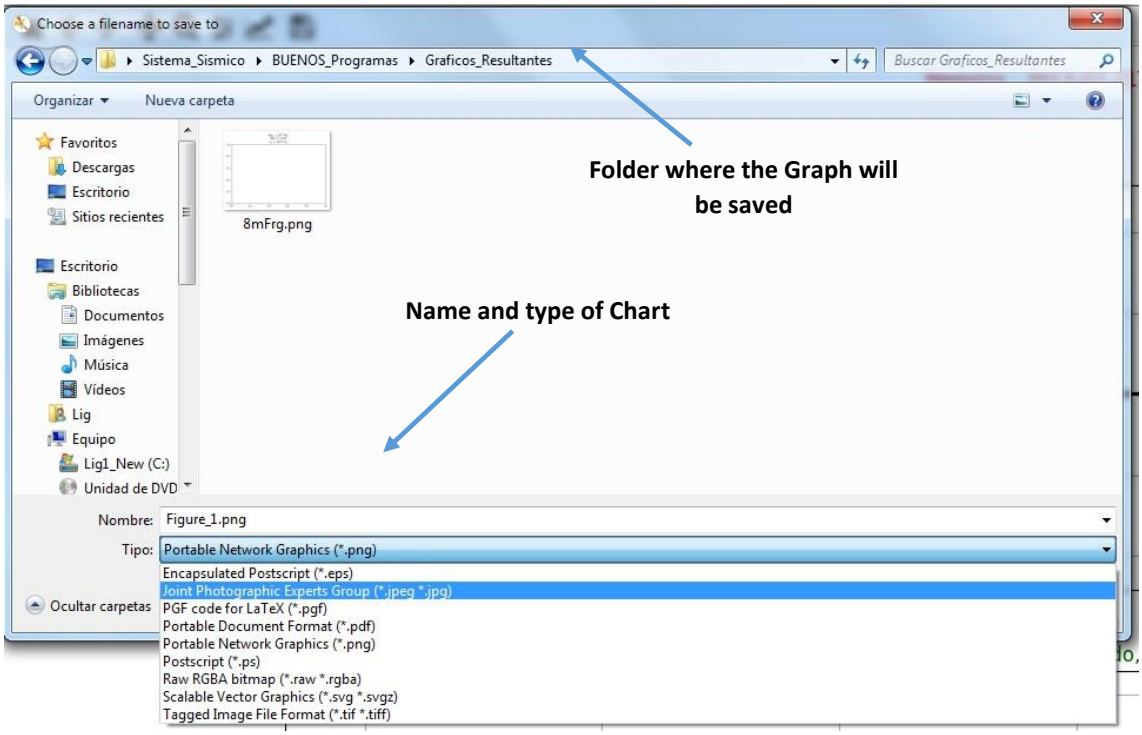


Fig. 86 Screen where you can see the types of formats available to save the graph.

The previous figure shows a list of the available file formats, the following image presents this list in more detail:

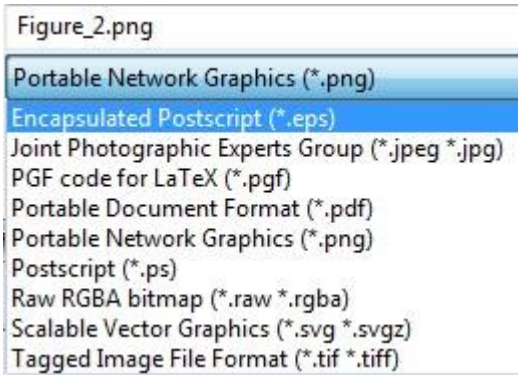
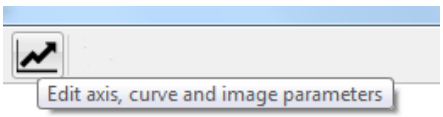


Fig. 87 List of available formats for saving the graph generated by the analysis.

Once you have selected both the name and the desired file format, and the location of the folder or directory where the graph will be saved, click the "*Save*" button (*See Fig. 85*), and the graph will be stored and available for further use as needed.

6.2.- Editing Axes and Images in Graphs

Through the "Edit" button, point 7 (*See page 66*) of the graph toolbar (*Edit axis, curve and image parameters*), it is possible to edit or modify the parameters of the axes, images, and curves of the graphs



For example, to modify the parameters of the image of a spectrogram, click on this command button. A "*Customize*" dialog box appears, indicating which of the "*axes*" in the graph areas you want to edit or modify. After selecting, click the "OK" button. This dialog box is similar to the following:

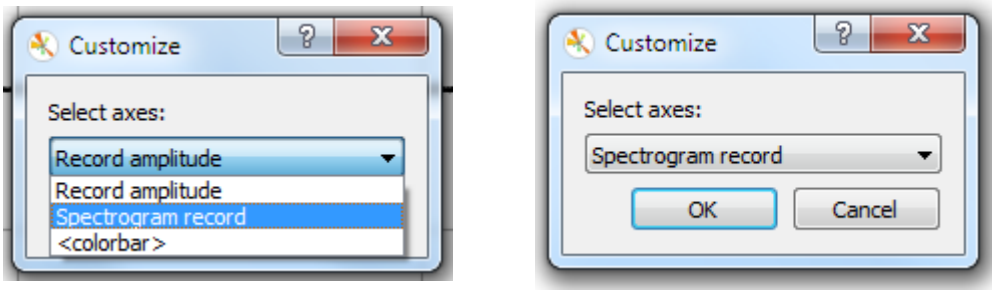


Fig. 88 Customize dialog box, the spectrogram axis has been selected.

Once the desired axis is selected, and the "OK" button is clicked, a new window with the options in the figure is presented. Here, various values of the selected axis are edited, in this case, the spectrogram (*Axes and Images*). The dialog box is as follows:

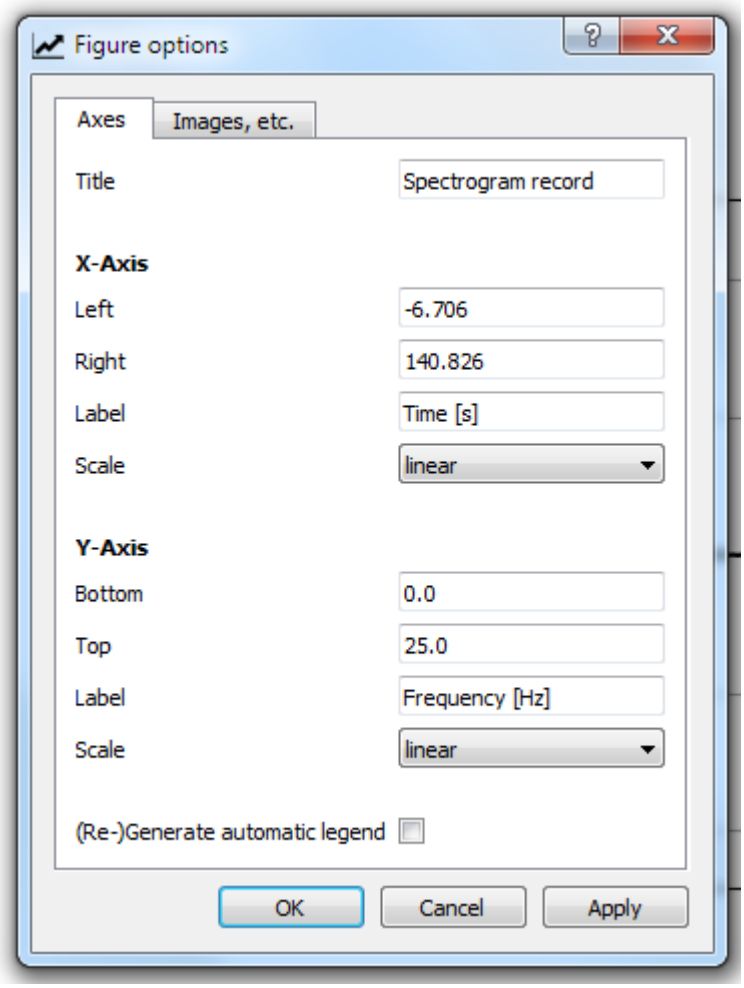


Fig. 89 Dialog box for editing options for the title and axes of the figure.

In this "*Axes*" section, as you can see, you can edit or modify the values or parameters of the title and the "X" and "Y" axes of the graph. For our example, we want to modify the image, so we will select the tab indicating this option. The image presented is as follows:

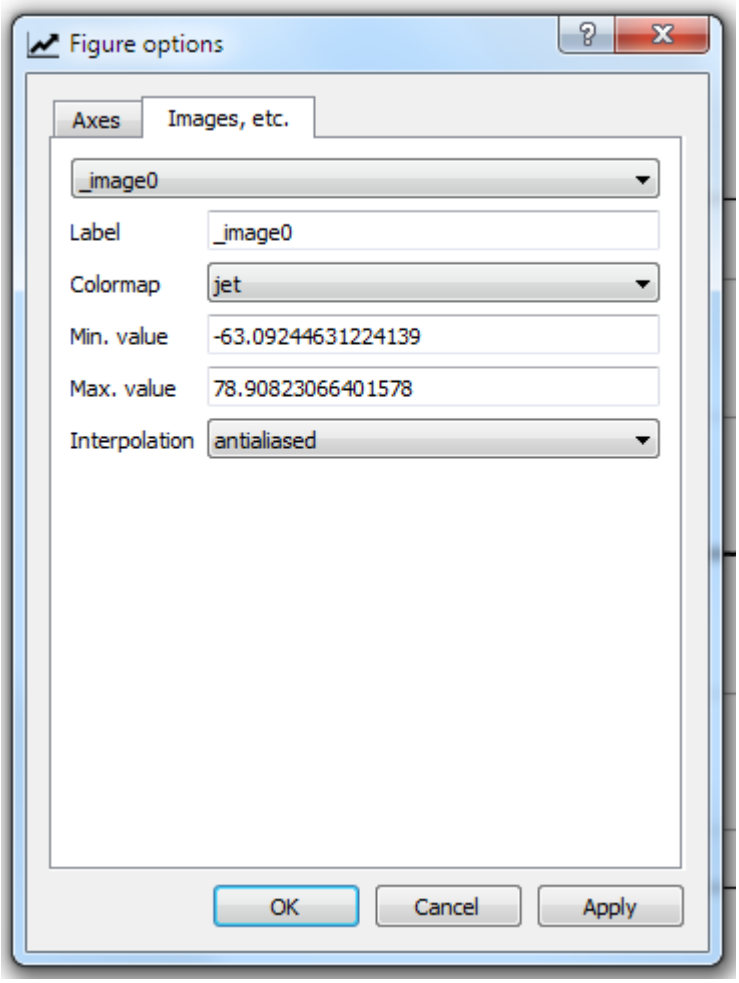


Fig. 90 Dialog box for editing options for image parameters.

As seen in the image, various parameters can be modified, including labels, the color map or "*Colormap*", used in the spectrogram, minimum and maximum values, and interpolation. The default value for the "*Colormap*" is set to "**jet**". The minimum and maximum values for this color map and the interpolation used are assigned by default to the image, but they can be modified according to the operator's interest.

The list of editable parameter values for both "*Colormap*" and "*Interpolation*" is presented in the figure on the next page.

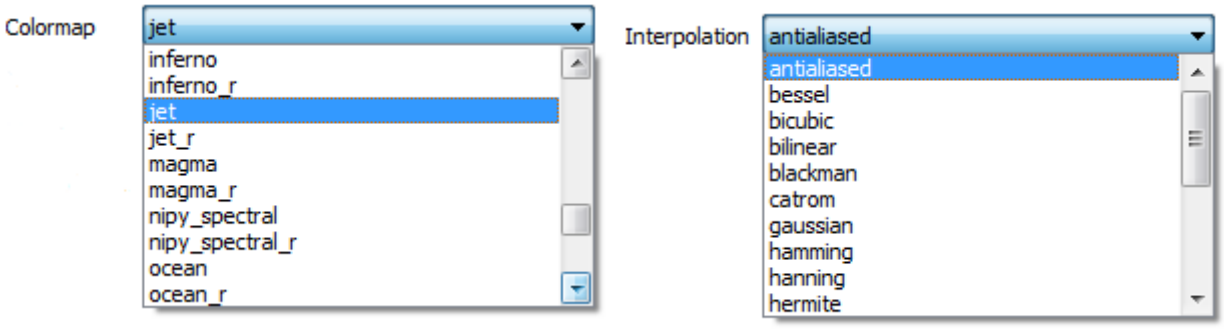


Fig. 91 Dialog boxes for editing some of the parameters of "*Colormap*" and "*Interpolation*" to select in the graph.

FINAL NOTE: The system is designed to be a user-friendly, accessible, and comprehensible tool. It offers reliable technological assistance to human operators in the analysis of both tectonic and volcanic seismic records, utilizing one or three components and digital filters. The simplicity of this initial version lies in its individual modules, which include various filter analyses and commonly used graphs in the study of seismic-volcanic signals. It includes the calculation and analysis of metrics such as Shannon Entropy, Frequency Index, and Kurtosis with their respective envelopes. Additionally, it establishes a comparative analysis of Shannon Entropy envelopes using various filter frequencies to determine which frequencies are most suitable for further studies. These metrics and tools are highly useful for establishing increasingly reliable and real-time alert models for future volcanic eruptions. In future versions or updates beyond the current version (1.1), extra modules can be added containing various types of analysis, functionalities, or different methods and algorithms, thereby improving seismic study and research for the benefit of the scientific community.

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END of the document.

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APPENDIX A

A1.- Installation of Python and Additional Libraries

A1.1. Package Content.

The main folder "*EntropySis1*" contains two subfolders for English and Spanish. Each subfolder includes the following:

a) Folder **"EntropySis1"**: (*Entropy seismic analysis system*). This folder must be copied to "*My Documents*". Contains the following elements:

a. Subfolder: "***Images***" Images necessary for program interfaces.
b. Program: ***Menu1.py***. Start and presentation program.
c. Program: ***class_canvas1.py***. Support program for the " *EntropySis1.py*" interface.
d. Program: "***ReadSignals1.py***". Module (interface) for reading, filtering, and plotting records with one or three components.
e. Program: "***Entropy1.py"***. Module (interface) for calculating, filtering, and plotting Shannon Entropy, Frequency index, Kurtosis and theirs envelope.
f. Program: "***EnvelopeFilter.py"***. Module (interface) for comparison, calculation, and plotting of Shannon Entropy envelopes using various filter frequencies.

b) Folder **"Document"**: containing:

a. User Manual: "***User_manual_Entropy1_ES1.pdf***" in PDF, written in Spanish.
b. User Manual: "***User_manual_Entropy1_EN1.pdf***" in PDF, written in English.
c. File "***Initials_requirements.txt***". File containing necessary libraries for installation on Windows using "Pip" after installing Python.
d. File "***README.txt***": File with general instructions for system installation.
e. File "***EntropySis1.bat***" (For Windows use): Batch processing executable file. Copy it to the desktop and run as administrator to start the system.

The system has all the elements (*programs and interfaces*) in English, except for the user manual, which is written in both Spanish and English. To install on Windows, two main actions should be taken after downloading and extracting the ". Rar" files. The first is to copy the entire folder (a) to the "*My Documents*" folder on the PC.

a) Copying the "*EntropySis1*" folder to "*My Documents*" in Windows from the downloaded (. Rar) file after extraction.
b) Copying the "*EntropySis1.bat*" file from the "(*Document*)" folder to the Windows desktop.

This ensures the proper use of the program. Now, we will proceed with the installation of the Python language and additional Python libraries on Windows.

A1.2.- Installing Python on Windows.

Python is an interpreted, multi-platform, and multiparadigm programming language (*it works on various operating systems, including Windows, Linux, and Mac*), utilizing two or more programming paradigms within a program-object-oriented, reflective, imperative, and functional.

In addition, Python can be enriched by a large number of programming modules, libraries, packages, or libraries installed through its package manager, "**Pip**." On Linux, the Python program and its manager "**Pip**" are installed together with the operating system. In Windows systems, however, where Python is not a native language, it is necessary to install this language beforehand by downloading the appropriate version from the Python distribution website at the following address: https://www.python.org/downloads/

On the website, the correct version should be selected based on the type of operating system on the computer, including whether it is 32 or 64 bits.

To be installed on both 32 and 64-bit systems, it is essential to note that this document and the software were created with the version available at that time, which was "*Python 3.8.6*", and many more versions have emerged since then. A more modern and adaptable version to the software (*recommended*) is "*Python 10.10*".

Users need to check if more advanced versions do not interfere with some of the installed libraries, such as "Obspy," for example. This is because everything related to Linux systems is constantly changing with updates that Python and Linux-based systems make. It is advisable to visit the website and download the most stable or tested updated version of Python that works well with this software.

Once downloaded, run it as an administrator (*right-click and "run as administrator"*), and the software installation wizard will guide you through the necessary steps (*just follow the instructions*).

The process takes only a few minutes. It is "recommended" to indicate during the process, when asked, to include an access path in the system's "**Path**" so that Python can be accessed from any location in Windows. If this is not done during the installation process, it must be done manually by modifying the environment variables (more complicated) to include the path from where Python is installed. This will not be necessary (*if indicated at the beginning*) through the installation wizard.

A1.3.- Installation of Additional Libraries.

The next step is to ensure that Python and its file manager or package manager (**Pip**) have been installed correctly. "**Pip**" (*file and library manager*) is crucial because it allows the installation of additional libraries that Python needs to run the created programs. To do this, open the Windows console window, or "*CMD*." The CMD, or command prompt, is a command-line interpreter.

Accessing the CMD is possible by typing, searching for the Windows logo key (a window), located between the "Ctrl" and "Alt" keys at the bottom left of the keyboard. Pressing this key, plus (+) the letter "**R**" key, will open a "Run" program window, similar to the following.

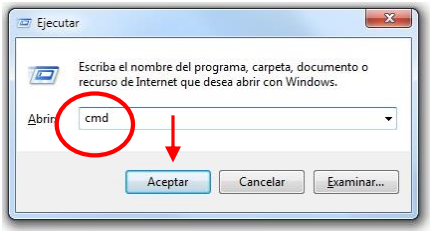

Fig. A1 Screen run in Windows. In the red circle, type "cmd" and click "OK."

As seen in the figure above, type "cmd," click "OK," which will open the Windows command prompt window.

Another way to do this is at the bottom of the desktop, in (W7) or next to (W10) the Windows "Start" button. There is the search section, indicated by the magnifying glass icon. This indicates a search for programs, similar to the following.

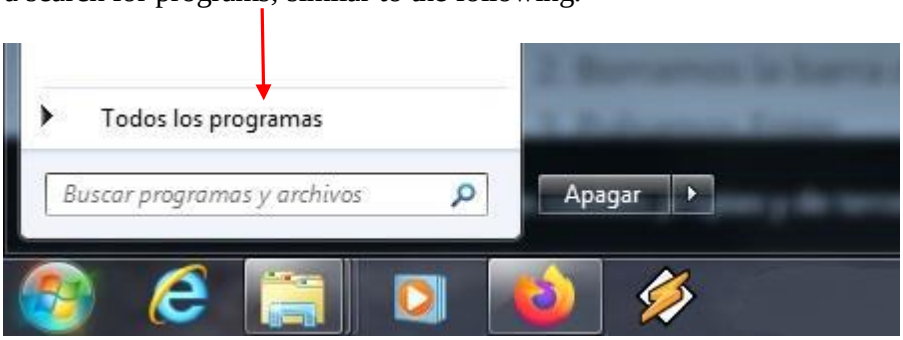

Fig. A2 Windows Program Search Screen.

In the box that says "Search programs and files" (Windows 7) or "*Type here to search*" (Windows 10), type "cmd" as well. This action or the previous one will bring up the Windows command prompt (CMD), similar to the following (W7).

Fig. A3 Windows 7 Command Prompt (CMD) Screen.

The same applies to versions: Windows 10 (W10) or Windows 11 (W11).

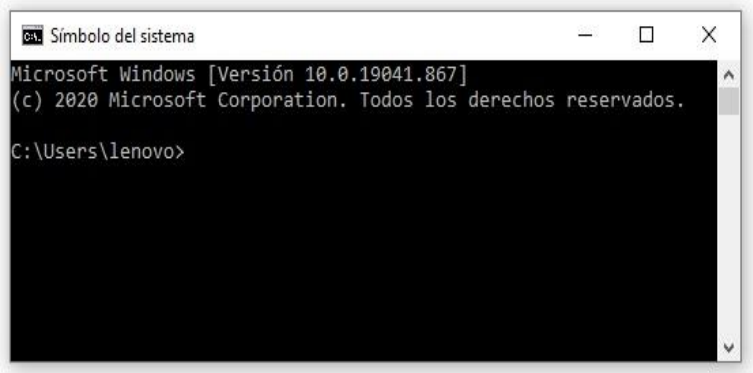

Fig. A4 Command Prompt (CMD) Screen in Windows 10.

Once on this screen, to verify that both Python and its package manager "pip" have been installed correctly, type the following commands: Python -V, and to check "pip," type: pip -V. This is shown in the following figure.

Fig. A5 CMD Screen, indicating Python and pip versions in Windows.

The output of typing "-V" in Python indicates invoking the installed version. In this case, it can be seen that it is "3.8.6" (*The library set is compatible with version 3.10.10*). This has been possible from any location in the system because the Python script has been installed, remember, in the "**path**" or route found in the system's environment variables. Also, after typing "pip -V", it can be seen that the Pip version is "*20.2.1*." At this point, it is recommended to update this version since, by default, "Pip" is installed along with "Python", but it does not install the latest or most up-to-date version. To do this, in the CMD window or console, type the following command (*Windows/Linux*): On Windows, type "python," and on Linux, type "python3".

Windows: > python –m pip install –upgrade pip | Linux: $ sudo python3 –m pip install –upgrade pip

This indicates that "Pip" will be updated to its most recent version (*On Linux, as a "superuser," i.e., with "sudo" at the beginning*). It is shown in the following screen.

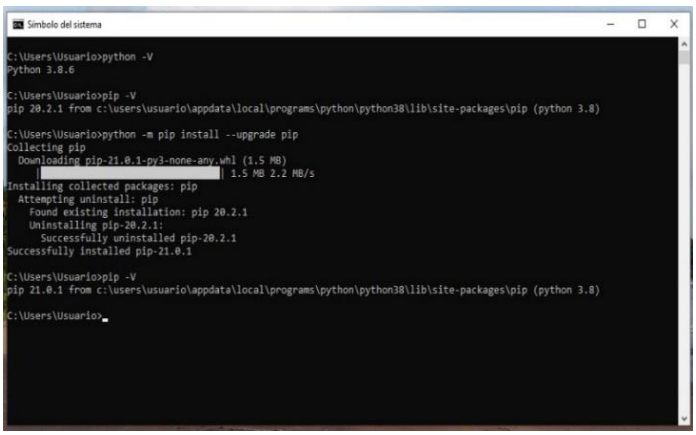

Fig. A6 Screen showing the update and verification of the new version of pip in Windows.

As can be seen, when typing again (**pip -V**), once Pip is updated, the version is 21.0.1. With this, Python and Pip are already installed and updated. Pip, as mentioned, is very important because with this manager, all the necessary libraries and packages are installed so that Python applications can be executed correctly and without errors. To use the system, you must proceed to install the necessary packages or libraries through Pip.

Next, we will proceed to explain how, in a simple and completely automatic way, the most commonly used and general libraries that Python needs will be installed on the system. Libraries such as, for example, "obspy," which is the open-source library or software based on Python for processing seismological data. Also, "matplotlib," which is a library for generating graphics from data contained in lists or arrays in Python and its mathematical extension "NumPy," among others, which the system needs for its execution (*See Annex B*).

A1.4 Automatic Installation of Libraries on Windows and Linux from PIP

The advantage of having already installed and updated Pip in Windows is that you can install all the libraries that Python needs to run the system.

Additionally, in the "*Document*" folder, the "*Readme.txt*" file contains instructions for this installation. So the user only needs to follow the instructions, and the necessary packages will be installed on the computer (PC) automatically by Pip, both on Windows and Linux. The required libraries are in the file called "***Initial_requirements.txt***", included in the "*Document*" folder of the downloaded installation files and in **Annex B**.

In a Windows Command Prompt (**Cmd**) window, actions are taken for each of the commands indicated in the file, following the instructions. The installation should not present problems on Windows and Linux systems. If any library encounters an error during installation (*shown in red in CMD*), you should consult the documentation for that library or check if the correct or recommended version of Python is being installed (*version 3.8.6 and/or 3.10.10*). The installation on Linux systems (*See README.txt*) is similar and simpler. Copy the main folder to the desktop, the personal folder, etc. From that location, open a command prompt, and simply type "$ python3 Menu1.py" to start the system.

APPENDIX B:

INSTALL PYTHON LIBRARIES FOR THE PROPER FUNCTIONING OF THE SYSTEM.

1.- PIP: The **Pip** (*Preferred Installer Program*) is the package or package management manager used to install and manage software packages written in Python. When installing Python, Pip is installed by default. To check the version of Python or PIP, type the following in a console or CMD:

python - V / pip – V And to see the list of installed pip packages: -> pip list

Usually, you need to update the version of pip with which Python is installed. For this, type the following command in the command prompt (CMD). In Linux and Mac systems, "sudo" is placed at the beginning to indicate super-user permissions.

Python –m pip install - - upgrade pip / (LINUX) -> sudo python –m pip install - - upgrade pip

Once downloaded and installed, you can check the version again with the first command, and you will see that the version has changed and been updated. Now that pip is updated, we will proceed to install the necessary packages for Python to work correctly with the applications.

2.- **PyQt Installation**: This is a Python binding for the Qt library written in the C++ language. It is used for creating and using graphical user interfaces (GUI) in Python. Type the following in the command prompt (CMD).

pip install PyQt5 / (LINUX & Mac) -> sudo python install PyQt5

3.- **Matplotlib library Installation**. Matplotlib is the library that allows the creation and visualization of graphics. Type the following:

pip install matplotlib / (LINUX & Mac) -> sudo python install matplotlib

4.- Install the **Obspy** library. This library is for handling seismic signals. Type the following:

pip install obspy / (LINUX & Mac) -> sudo python install obspy

5.- Install **Thinter**: Thinter is a graphical user interface (GUI). Type the following:

pip install tk / (LINUX & Mac) -> sudo python install tk

6.- Install **quantecon**: This library is used for spectrum estimation, Periodogram, Fourier transform. Type the following:

pip install - - upgrade quantecon / (LINUX & Mac) -> sudo python install - - upgrade quantecon

7.- Update a library for **matplotlib**. To avoid problems with graphics, install the following:

pip install msvc-runtime / (LINUX & Mac) -> sudo python install msvc-runtime

8.- Install **easygui** for the graphical interface:

pip install easygui / (LINUX & Mac) -> sudo python install easygui

9.- Install **PyWavelets** for CWT handling.

pip install PyWavelets / (LINUX & Mac) -> sudo python install PyWavelets

10.- Install **plotly** for handling and assisting with graphics along with Matplotlib.

pip install plotly / (LINUX & Mac) -> sudo python install plotly

Finally, type "pip list" to see the installed libraries. Optionally, you can create a file called "***requirements.txt***" that will contain all the libraries that the PC will use. The "***requirements.txt***" file must be in the current directory. The instruction to do this is as follows:

pip freeze > requirements.txt